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 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.

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 1
Introduction

Release of the *Next Generation Science Standards* (*NGSS*) in April 2013 generated a variety of questions for the science education community. Constructive responses to science teachers, science coordinators, and curriculum developers' questions and their related concerns will be critical to a successful reform. Among the questions central to the science education community were variations on the following:

- How will the *NGSS* affect my teaching?
- How do I translate the standards to classroom instruction?
- Are there instructional materials that align with the standards?
- How does my teaching (at the elementary, middle, or high school level) fit into the K–12 science curriculum?
- Will national, state, district, and classroom assessments change?
- How can the standards in the *NGSS* be used to create school programs and curriculum materials for classroom instruction?

All of us in the science education community must take such questions seriously. Furthermore, we must provide constructive, appropriate, and practical answers. These questions are timely and important as the daily task of science teaching centers on teachers providing opportunities for students to learn the science and engineering practices, crosscutting concepts, and disciplinary core ideas of the *NGSS*. Briefly, the teachers' concerns are about curriculum, instruction, and assessment, all of which are addressed in this book.

With the background of questions from teachers, one must recognize the reality of assessment as a dominant force in contemporary education. The *NGSS* are expressed as performance expectations integrating the practices, crosscutting concepts, and disciplinary core ideas. Performance expectations are, at a minimum, related to assessments and can appropriately be viewed as assessment standards. So, one can expect that assessments based on the *NGSS* will be developed. This also answers one question asked by science teachers: Yes, assessments will change. Accountability models are changing as well. Not only will assessments change, but the accountability models that have so clearly emphasized single large-scale assessment scores likely also will change.

In developing this book, I recognized the importance of assessments. In response, I have included units and items where appropriate. For example, the organization Measured Progress provided physical science examples for grade 5, middle school, and high school (see Appendixes A, B, and C). In addition, through work for the Council of Chief State School Officers (CCSSO) the organization David Heil and Associates developed several assessments based on the *NGSS*. I have included those in different chapters. These are initial efforts to change assessments.

There remains another question: What about curriculum and instruction? This book provides preliminary answers to questions about school curricula and classroom instruction. I underscore the word *preliminary* and emphasize the fact that my response is intended to help science teachers and others in the science education community begin thinking about translating the standards to classroom instruction. An important place to begin is an understanding of standards for science education. In the time between standards adoption and assessment development, it may be tempting to wait for the assessments before contemplating changes to curriculum and instruction. Our current accountability system has taught teachers, curriculum directors, and the science education community that assessments drive the curriculum. However, now is the time for teachers, local education agencies, state departments of education, and multistate collaborations to evaluate changes to curriculum and instruction to prepare students for the 21st century.

STANDARDS FOR SCIENCE EDUCATION

In the early 1990s, I began working on the *National Science Education Standards* (*NSES*; NRC 1996) as chair of the content working group. In 1995, Diane Ravitch published *National Standards in American Education: A Citizen's Guide,* which stimulated a national conversation about standards. As a participant in that conversation, I soon realized several objections to national standards for science education. For example, some expressed concerns about the imposition of unwanted values, the potential of a national curriculum, the priority of states' rights, the reduction of equality of opportunity, and the very real concern that national standards for science education, taken on their own, will stand as policies without aligned curriculum programs and reformed classroom practices. These and other concerns also describe some of the contemporary challenges of the *NGSS*.

In the two decades of work on science education standards, I have come to recognize the long-term positive influence of national standards for science education. First, national standards can influence *all* of the key components of the education system. Second, they clarify the most fundamental goals—learning outcomes for all students. Third, standards at the national level are necessary for equality of educational opportunity. Finally, while curriculum emphasis may vary, I find little reason to have significant variations among national, state, and local content standards for science because the basic concepts and practices of science are common and do not vary based on state or region.

The fundamental idea underlying the standards is to describe clear, consistent, and challenging goals for science education. Then, based on the standards, we need to reform school science curricula and classroom instruction to enhance student learning. It seems to me that clear and consistent goals and greater coherence in curriculum, teaching, and assessments increase the possibilities for higher levels of achievement for all students.

How should one think about and evaluate the potential influence of the *NGSS*? An adequate evaluation of using standards as a basis for reform rests on the effects that the standards have on science curriculum, science teaching, science teachers, science assessments, and, ultimately, students learning science. In the United States, numerous and varied reform efforts have had little effect on teaching and learning in classrooms. Richard Elmore and Milbrey McLaughlin express the fundamental issue quite insightfully:

> Reforms that deal with the fundamental stuff of education—teaching and learning—seem to have weak, transitory, and ephemeral effects; while those that expand, solidify, and entrench school bureaucracy seem to have strong, enduring, and concrete effects. (Elmore and McLaughlin 1988, p. V)

In 1988, Elmore and McLaughlin identified a problem that persists to this day. Science educators simply must get to the essential components of reform. The *NGSS* move the conversation to curriculum and instruction and the potential to collaborate on a much grander scale. If curricular and instructional resources are based on *NGSS*, there is great potential for quality programs. I argue that standards for science education are necessary—but not sufficient—for the improvement of student achievement. To be clear, the problems of education reform require systemic solutions. One person, one book, or one initiative will not solve the complex problems that attend a goal of improving students' achievement in science. This book addresses one requirement of reform—translating standards to school curriculum and classroom instruction.

SOME BASIC FEATURES AND PRINCIPLES OF THE NGSS

What is the argument for adoption of the *NGSS*? How does the science education community know that using standards as the basis for curriculum materials will make things better? In short, will national standards enhance student learning? On the face of it, these questions seem to be both simple and specific. That said, the answers are both complex and broad. The discussion that follows relies on a combination of evidence, common sense, reason, and intuition.

The *NGSS* provide a powerful set of policies to guide the improvement of science education. As important and challenging as the development of the *NGSS* is, the standards represent only one step in the progress of standards-based improvement of science education. Although many different steps must follow publication, it seems particularly important to pause briefly and examine some features and principles of the *NGSS*.

The *NGSS* specifically include features that address issues associated with implementation. From the beginning, all those involved with the development of *NGSS* recognized that the influence of standards was broader than the content and curriculum—that is, one had to consider the contemporary education system within which the standards would facilitate change. Figure 1.1 describes several basic features of the *NGSS*.

FIGURE 1.1. SEVERAL BASIC FEATURES OF THE *NGSS*

The *NGSS* are based on the following foundational ideas:

- Present performance expectations for all students.
- Describe policies and not a curriculum.
- Clarify equity and excellence.
- Integrate engineering with science.
- Provide guidance for college and career readiness.

Like earlier national and state standards for science education, the *NGSS* are policies that must be translated to be implemented by supervisors, coordinators, and teachers.

A NOTE ON TRANSLATING STANDARDS TO CLASSROOM INSTRUCTION

The original title for this book was *From the* Next Generation Science Standards *to Classroom Practices*. The title expressed the book's general theme, but then I needed to answer questions about the processes and criteria that began with national standards and resulted in classroom instruction. What best describes the process? Does the term *implementing* work? Is *interpreting* more accurate? How about *transforming* or *explaining*? Although each of these terms presents a reasonable possibility, I found *translating* to be the most appropriate. Before we have a discussion of translation, however, let me digress and provide a context.

For some time, I have found it quite helpful to use a model of different dimensions of education systems. I refer to the model as the 4*P*s, and descriptions of the dimensions center on the terms *purposes*, *policies*, *programs*, and *practices* (see Bybee 1997; 2010). Figure 1.2 summarizes the four dimensions.

We have the *NGSS*. Now we must turn to the task of translating the standards from policies to school programs (i.e., curricula) and classroom practices (i.e., instruction). This brings us back to the process of translating.

FIGURE 1.2. THE 4*P*S: PURPOSES, POLICIES, PROGRAMS, AND PRACTICES

Purposes

Purpose statements define aims, goals, and rationales. These statements tend to be universal and abstract and apply to all components of the science education system (e.g., teacher education, curriculum, instruction, and assessment). Although it presents elements of both purpose and policy, *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012) has served as the purpose and vision in this era of standards-based reform.

Policies

Policies are more specific statements of the purpose. Standards, benchmarks, syllabi, and action plans based on the defined purposes are policies. Policy statements are concrete translations of the purpose and apply to specific components such as teacher education, K–12 curriculum, state assessments, and classroom instruction. The *NGSS* provide the policy statement most applicable to this discussion.

Programs

Programs are the actual materials, books, and software used in states, schools, and classrooms. Programs are unique to disciplines, K–12 grades, and different levels in the education system. Curriculum materials for K–12 science and state assessments are different examples of programs. Programs are a translation of policies to fit unique requirements.

Practices

Practices refer to the specific actions of educators as they bring a program's potential to reality. Classroom instruction of science is an example of practices. Practices are the most unique and fundamental level of translation.

The task of translating the *Framework* to *NGSS* and *NGSS* to school curriculum and classroom instruction has some characteristics in common with the process of translating a book from one language to another. The challenges of translating include expressing one language and core ideas in another language while retaining the original intention and meaning. One must note that fluency in both languages is required, and there must be an understanding and sensitivity for any unusual concepts and cultural subtleties that cannot be directly translated but must be conveyed or expressed in the translation. In the case of the *NGSS*, there is the challenge of trying to translate policies with the subtleties and complexities of a Shakespearean play. In the process of translating standards to curriculum (i.e., programs) and instruction (i.e., practices), one must endeavor to understand standards as policies and the requirements of school programs and classroom practices.

In translating standards, there are limits and possibilities; something will be lost and something gained. From the beginning, one must realize that the only thing that exactly aligns with the *NGSS* are the *NGSS*. Still, the *NGSS* should be the guide and the translations must represent the intentions of the standards. With a clear understanding of *NGSS*, the results should be accurate, reasonable, and responsible translation. With that said, the *NGSS* present a complex set of concepts and practices combined in performance expectations that are intended for assessment but have implications for curriculum and instruction.

A First Engagement: Translating Performance Expectations to Classroom Instruction

Table 1.1 presents an initial and simplified challenge of translating standards to programs and practices. I encourage you to take a few minutes and complete the task of translating the standard to an instructional sequence. Answering the questions will give you some insights about the challenges of moving from *NGSS* to classroom instruction and engage you in the themes of this book.

The challenge is to translate the performance expectations into an instructional sequence that will provide adequate opportunities for students to learn the content of this standard.

Here are a few helpful suggestions. Begin by reading the two performance expectations, including the clarifying statements and assessment boundaries (i.e., 4ESS3-1 and 4ESS3-2). Next, identify the science and engineering practices, disciplinary core ideas, and crosscutting concepts in the two performance expectations. Look at the foundation boxes for further clarification of content for the practices, ideas, and concepts in the performance expectation.

A useful perspective is to approach the translation as a sequence of lessons, not a lesson for each performance expectation. Understanding of the practices, ideas, and concepts should be developed using multiple lessons in a carefully designed sequence.

Briefly describe your plans for an instructional sequence.

- Beginning of instructional sequence:
- Middle of instructional sequence:
- Conclusion of instructional sequence:

For students to meet the requirements described in the performance expectation, what did the teacher do? What did the students do? How would you determine if the students can demonstrate the understandings described in the performance expectations? Briefly complete Table 1.2 (p. 8).

How would you assess student learning? What would you design as an assessment that provides acceptable evidence that students have learned the science and engineering practices, disciplinary core ideas, and crosscutting concepts in the

TABLE 1.1. TRANSLATING 4-ESS3 EARTH AND HUMAN ACTIVITY TO CLASSROOM INSTRUCTION

4-ESS3 Earth and Human Activity

4-ESS3 Earth and Human Activity

Students who demonstrate understanding can:

4-ESS3-1. Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment. [Clarification Statement: Examples of renewable energy resources could include wind energy, water behind dams, and sunlight; non-renewable energy resources are fossil fuels and fissile materials. Examples of environmental effects could include loss of habitat due to dams, loss of habitat due to surface mining, and air pollution from burning of fossil fuels.]

4-ESS3-2. Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.* [Clarification Statement: Examples of solutions could include designing an earthquake resistant building and improving monitoring of volcanic activity.] [Assessment Boundary: Assessment is limited to earthquakes, floods, tsunamis, and volcanic eruptions.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems. ▪ Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution. (4-ESS3-2) **Obtaining, Evaluating, and Communicating Information** Obtaining, evaluating, and communicating information in 3–5 builds on K–2 experiences and progresses to evaluate the merit and accuracy of ideas and methods. ▪ Obtain and combine information from books and other reliable media to explain phenomena. (4-ESS3-1)	**ESS3.A: Natural Resources** ▪ Energy and fuels that humans use are derived from natural sources, and their use affects the environment in multiple ways. Some resources are renewable over time, and others are not. (4-ESS3-1) **ESS3.B: Natural Hazards** ▪ A variety of hazards result from natural processes (e.g., earthquakes, tsunamis, volcanic eruptions). Humans cannot eliminate the hazards but can take steps to reduce their impacts. (4-ESS3-2) *(Note: This Disciplinary Core Idea can also be found in 3.WC.)* **ETS1.B: Designing Solutions to Engineering Problems** ▪ Testing a solution involves investigating how well it performs under a range of likely conditions. *(secondary to 4-ESS3-2)*	**Cause and Effect** ▪ Cause and effect relationships are routinely identified and used to explain change. (4-ESS3-1) ▪ Cause and effect relationships are routinely identified, tested, and used to explain change. (4-ESS3-2) -- ***Connections to Engineering, Technology, and Applications of Science*** **Interdependence of Science, Engineering, and Technology** ▪ Knowledge of relevant scientific concepts and research findings is important in engineering. (4-ESS3-1) **Influence of Science, Engineering and Technology on Society and the Natural World** ▪ Over time, people's needs and wants change, as do their demands for new and improved technologies. (4-ESS3-1) ▪ Engineers improve existing technologies or develop new ones to increase their benefits, to decrease known risks, and to meet societal demands. (4-ESS3-2)

Connections to other DCIs in fourth grade: **4.ETS1.C** (4-ESS3-2)

Articulation of DCIs across grade-levels: **K.ETS1.A** (4-ESS3-2); **2.ETS1.B** (4-ESS3-2); **2.ETS1.C** (4-ESS3-2); **5.ESS3.C** (4-ESS3-1); **MS.PS3.D** (4-ESS3-1); **MS.ESS2.A** (4-ESS3-1),(4-ESS3-2); **MS.ESS3.A** (4-ESS3-1); **MS.ESS3.B** (4-ESS3-2); **MS.ESS3.C** (4-ESS3-1); **MS.ESS3.D** (4-ESS3-1); **MS.ETS1.B** (4-ESS3-2)

Common Core State Standards Connections:

ELA/Literacy –

RI.4.1	Refer to details and examples in a text when explaining what the text says explicitly and when drawing inferences from the text. (4-ESS3-2)
RI.4.9	Integrate information from two texts on the same topic in order to write or speak about the subject knowledgeably. (4-ESS3-2)
W.4.7	Conduct short research projects that build knowledge through investigation of different aspects of a topic. *(4-ESS3-1)*
W.4.8	Recall relevant information from experiences or gather relevant information from print and digital sources; take notes and categorize information, and provide a list of sources. (4-ESS3-1)
W.4.9	Draw evidence from literary or informational texts to support analysis, reflection, and research. *(4-ESS3-1)*

Mathematics –

MP.2	Reason abstractly and quantitatively. *(4-ESS3-1),(4-ESS3-2)*
MP.4	Model with mathematics. *(4-ESS3-1),(4-ESS3-2)*
4.OA.A.1	Interpret a multiplication equation as a comparison, e.g., interpret 35 = 5 × 7 as a statement that 35 is 5 times as many as 7 and 7 times as many as 5. Represent verbal statements of multiplicative comparisons as multiplication equations. (4-ESS3-1),*(4-ESS3-2)*

performance expectations? Briefly describe how you would assess the performance expectations.

Describe the challenges you encountered in translating the standard. Were these challenges of vocabulary? Science content? Architecture of the standard? Other? What was lost and gained in the translation?

Now that you have an initial experience with the challenge of translating *NGSS* to classroom instruction, we will continue with an introduction to the perspectives and plans for this book.

TABLE 1.2. SUMMARY OF CLASSROOM INSTRUCTION

Lessons	Classroom Instruction	Dimensions of Performance Expectations		
		Science and engineering practice	Disciplinary core idea	Crosscutting concept
Lesson 1	What the teacher did			
	What the students did			
Lesson 2	What the teacher did			
	What the students did			
Lesson 3	What the teacher did			
	What the students did			
Lesson 4	What the teacher did			
	What the students did			
Lesson 5	What the teacher did			
	What the students did			
Lesson 6	What the teacher did			
	What the students did			
Add additional lessons if needed.				

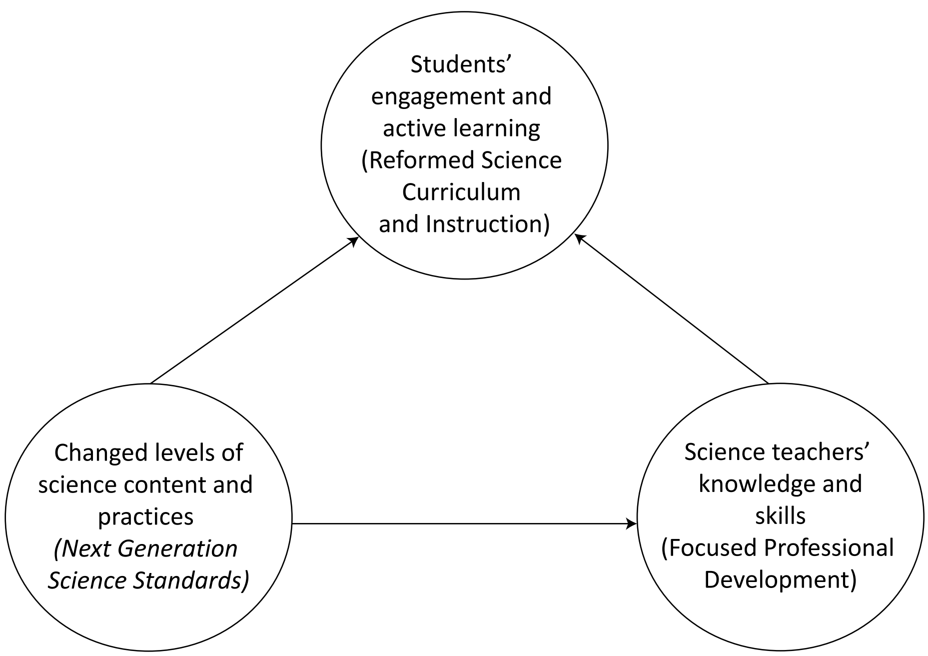
FOCUS ON THE INSTRUCTIONAL CORE

Richard Elmore (2009) introduced the term *instructional core* as a response to issues of improving student learning at scales that make a difference. Here is a clear statement that makes Elmore's fundamental point:

> There are only three ways to improve student learning at scale: You can raise the level of content that students are taught. You can increase the skill and knowledge that teachers bring to the teaching of that content. And you can increase the level of students' active learning of the content. (Elmore 2009, p. 24)

You can see that focusing on the instructional core means acknowledging the complex and difficult work of science teaching and student learning. Put simply, the role of science teaching is too important to avoid and too critical to misrepresent. Figure 1.3 presents the instructional core.

FIGURE 1.3. INSTRUCTIONAL CORE OF PRACTICE FOR SCIENCE TEACHING



I have since used the concept of the instructional core as a way to direct attention to the essentials of improving student learning—content, curriculum, and teachers' knowledge and skills for teaching content (Bybee 2010).

The *NGSS* change the rigor, focus, and depth of science content. There is a need to increase students' active learning of the science content, and for me, this directly implies changes in curriculum, instruction, and assessments in science classrooms.

Finally, there is a need for professional development of science teachers relative to content in the *NGSS.*

Think of a three-legged stool. In this case, the three legs are science content described in the *NGSS*, science curriculum and instruction, and science teachers' knowledge and skills for teaching content. In the world of three-legged stools, there is a law—not a hypothesis or theory—that once you change one leg, you must change the other two, if your goal is stability after the initial change. The *NGSS* have changed one leg of the instructional core. Now the science education community must address changes in school curricula, classroom instruction, and the knowledge and skills of science teachers.

It is time we stop and ask, "What counts as student improvement?" The answer I propose is student achievement. Whether determined by results on quizzes, unit tests, state assessments, the National Assessment of Educational Progress (NAEP), or international assessments such as TIMSS (Trends in International Mathematics and Science Study) or PISA (Program for International Student Assessment), student achievement is what counts. This discussion leads to another question: What can the science education community do to improve student achievement at a scale that makes a difference? My answer, again, is to attain higher levels of student achievement by focusing on the instructional core. With publication of the *NGSS*, we have changed the content leg, and this book directs attention to the means that teachers use to engage and increase students' active learning—that is, curriculum, instruction, and assessment.

THE PLAN FOR THIS BOOK

The chapters in this book address issues raised by science teachers. My response is intended to help the "first responders" think about translating standards to classroom instruction. The chapters serve three purposes:

1. They answer questions about translating standards to classroom practices.
2. They give insights about reforming curriculum for schools, districts, and states.
3. They provide examples of curriculum, instruction, and assessment.

The book is divided into three parts, and readers may read and use the parts and chapters on a "need to know and do" basis. The first part, which includes this chapter and Chapters 2 and 3, presents an introduction to the *NGSS*. Chapter 2 uses a life sciences context to introduce *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012), which served as the basis for the *NGSS*. The architecture of the standards is described, as are the language and contexts needed for the translation and use of standards in school science programs. Chapter 3, "*NGSS*: 10 Frequently Answered Questions," takes a broader view and provides further introduction to the *NGSS.*

The second part of the book includes Chapters 4–7. Chapter 4 introduces some fundamentals for moving from *NGSS* to classrooms, and Chapters 5–7 describe translations of standards to elementary, middle, and high school classroom practices, respectively. The chapters illustrate what translating the standards might look like in classrooms. The chapters should be quite meaningful for teachers of science because they show how the standards can be translated and implemented in classrooms. I tried to use simple and, in some cases, common examples for the lessons that form the heart of these chapters. The use of such lessons was intentional, as I wanted to show that science teachers can begin implementing the standards without adopting entirely new programs. I think this approach is prudent in light of the immediate need to begin implementing *NGSS* and the fact that states and school districts are operating in an era of budget constraints. In addition, the lessons do include assessments. I should note that I developed the assessments and then used backward design to adapt the individual lessons and instructional sequence.

Although I realize that elementary school teachers of science will be most interested in Chapter 5, middle school science teachers in Chapter 6, and high school science teachers in Chapter 7, I encourage all readers to at least review all three chapters because they address one category of content and present a general learning progression across the elementary to high school continuum.

The book's third part begins with Chapter 8. Part 3 presents a process of translating standards to school programs and classroom instruction, which is the theme of Chapters 8–10. For me, the challenge of actualizing the standards in instructional sequences was profound. The lessons I learned should help those who will have to do what I did. Integrating the three dimensions of *NGSS*—science and engineering practices, crosscutting concepts, and disciplinary core ideas—requires consideration and understanding of the form and function of classroom activities and use of an integrated instructional sequence.

Chapters 8–10 build on the insights gained in developing the examples in Chapters 5–7. The aim in Chapters 8–10 is to provide guidance for those who have the challenge of translating standards by adapting curriculum materials based on the *NGSS*. Due to the time required for the development of new programs, the primary emphasis in these chapters is on adapting current lessons and units of instruction.

I realize that the changes required by the *NGSS* may raise concerns in the science education community in general and among classroom teachers in particular. Often these concerns are expressed as *Yes, but ...* comments. In Chapter 11, I address some commonly expressed concerns.

The concluding chapter discusses the *NGSS* and the possibilities of their influence on the education system.

CONCLUSION

From the late 1980s to the present, K–12 science teachers and the larger science education community have witnessed an era of standards-based reform. Basically, the idea is to develop clear, comprehensive, and challenging goals for student learning. Beyond learning goals, the implicit assumption is that standards would be used to make other components of the education system more coherent. Curriculum, instruction, assessments, and the professional development of teachers would be aligned. Common sense supports this view. But in education reform, common sense does not always carry the day.

Relative to the *NGSS*, I am particularly concerned about one question science teachers frequently ask: Where are the curriculum materials that will help me implement *NGSS* in my classroom? Their second question usually is,Will the assessments change? These are both critical questions. I recognize several initiatives relative to assessment but provide few discussions of new instructional materials. My purpose in writing this book is to help the science education community address the critical issue of curriculum reform.

I cannot emphasize enough the need for clear and coherent curriculum and instruction that connect standards and assessments. Curriculum materials will be the missing link if they are not developed and implemented. The absence of a curriculum based on *NGSS* will be a major failure in this era of standards-based reform and assessment-dominated results. When science teachers at all levels of K–12 ask, "Where are the materials that help me teach to the standards?" the education system must have a concrete answer.

The instructional materials may be adapted from current programs, provided by states, or developed by professional organizations. They may come as print books or e-books or other electronic formats. But they must be available. At a minimum, model units are needed as soon as possible. Arguing for a coherent curriculum based on the standards is not new. Indeed, there is a long history of curriculum serving an essential role in science teaching. If there is no curriculum for teachers, I predict the standards will be implemented with far less integrity than intended by the NRC *Framework* and those who developed the *NGSS*.

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CHAPTER 2

From *A Framework for K–12 Science Education* to the *Next Generation Science Standards*

Just as the first generation of national standards influenced state-level standards, assessments, and science teachers at all levels K–12, so too will the *Next Generation Science Standards* (*NGSS*). In fact, many states have adopted the *NGSS* as their standards.

This chapter first reviews essential features of *A Framework for K–12 Science Education* (NRC 2012), which provides a foundation for the *NGSS*. Second, the chapter describes the important features of *NGSS*. Finally, I discuss several implications of the new standards. This chapter is based on other discussions of biology and the *NGSS* (see Bybee 2011b; 2012; 2013). *The NSTA Reader's Guide to the* Next Generation Science Standards (2013) by Harold Pratt also provides an excellent introduction to *NGSS*.

A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC 2012) has three parts. The first part sets out a vision for science education that includes the guiding assumptions and organization. Part 2 provides the content for the science and engineering education. Finally, Part 3 addresses the means to realize the vision by addressing the integration of content, implementation, equity, and guidance for the *NGSS*.

The *Framework* describes three essential dimensions: science and engineering practices, crosscutting concepts, and core ideas in science disciplines. Although all three disciplines are introduced, for purposes of clarifying the discussion and consistency across the K–12 continuum, detailed discussions in this chapter cover the life sciences.

SCIENTIFIC AND ENGINEERING PRACTICES

This discussion of scientific and engineering practices is adapted from an earlier NSTA publication (Bybee 2011). Because the practices represent an important innovation for the *NGSS*, one that science teachers will have to understand and apply, I elaborate on the practices and briefly describe what students should know and be able to do and examples of how they might be taught. In Figures 2.1 through 2.8 (pp. 16–18), I summarize scientific and engineering practices from *A Framework for K–12 Science Education* (NRC 2012). Some changes have been made to the original figures for clarity and balance, but the substantive content has been maintained.

FIGURE 2.1. ASKING QUESTIONS AND DEFINING PROBLEMS

Science begins with a question about a phenomenon, such as "Why is the sky blue?" or "What causes cancer?" A basic practice of scientists is the ability to formulate empirically answerable questions about phenomena to establish what is already known and determine what questions have yet to be satisfactorily answered.	**Engineering** begins with a problem that needs to be solved, such as "How can we reduce the nation's dependence on fossil fuels? or "What can be done to reduce a particular disease?" or "How can we improve the fuel efficiency of automobiles?" A basic practice of engineers is to ask questions to clarify the problem, determine criteria for a successful solution, and identify constraints.

FIGURE 2.2. DEVELOPING AND USING MODELS

Science often involves the construction and use of models and simulations to help develop explanations about natural phenomena. Models make it possible to go beyond observables and simulate a world not yet seen. Models enable predictions of the form "If … then … therefore" to be made to test hypothetical explanations.	**Engineering** makes use of models and simulations to analyze extant systems, identify flows that might occur, or test possible solutions to a new problem. Engineers design and use models of various sorts to test proposed systems and recognize the strengths and limitations of their designs.

FIGURE 2.3. PLANNING AND CARRYING OUT INVESTIGATIONS

Scientific investigations may be conducted in the field or the laboratory. A major practice of scientists is planning and carrying out systematic investigations that require clarifying what counts as data and in experiments identifying variables.	**Engineering investigations** are conducted to gain data essential for specifying criteria or parameters and to test proposed designs. Like scientists, engineers must identify relevant variables, decide how they will be measured, and collect data for analysis. Their investigations help them identify the effectiveness, efficiency, and durability of designs under different conditions.

FIGURE 2.4. ANALYZING AND INTERPRETING DATA

Scientific investigations produce data that must be analyzed to derive meaning. Because data usually do not speak for themselves, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Sources of error are identified and the degree of certainty is calculated. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis.	**Engineering investigations** include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria—that is, which design best solves the problem within given constraints. Like scientists, the engineers require a range of tools to identify the major patterns and interpret the results. Advances in science make analysis of proposed solutions more efficient and effective.

FIGURE 2.5. USING MATHEMATICS AND COMPUTATIONAL THINKING

In **science**, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; statistically analyzing data; and recognizing, expressing, and applying quantitative relationships. Mathematical and computational approaches enable prediction of the behavior of physical systems along with the testing of such predictions. Moreover, statistical techniques are also invaluable for identifying significant patterns and establishing correlational relationships.	In **engineering**, mathematical and computational representations of established relationships and principles are an integral part of the design process. For example, structural engineers create mathematics-based analysis of designs to calculate whether they can stand up to expected stresses of use and if they can be completed within acceptable budgets. Moreover, simulations provide an effective test bed for the development of designs as proposed solutions to problems and their improvement, if required.

FIGURE 2.6. CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

The goal of **science** is the construction of theories that provide explanatory accounts of the material world. A theory becomes accepted when it has multiple independent lines of empirical evidence, greater explanatory power, a breadth of phenomena it accounts for, and explanatory coherence and parsimony.	The goal of **engineering design** is a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. Usually there is no one best solution, but rather a range of solutions. The optimal choice depends on how well the proposed solution meets criteria and constraints.

FIGURE 2.7. ENGAGING IN ARGUMENT FROM EVIDENCE

In **science**, reasoning and argument are essential for clarifying strengths and weaknesses of a line of evidence and for identifying the best explanation for a natural phenomenon. Scientists must defend their explanations, formulate evidence based on a solid foundation of data, examine their understanding in light of the evidence and comments by others, and collaborate with peers in searching for the best explanation for the phenomena being investigated.	In **engineering**, reasoning and argument are essential for finding the best solution to a problem. Engineers collaborate with their peers throughout the design process, with a critical stage being the selection of the most promising solution among a field of competing ideas. Engineers use systematic methods to compare alternatives, formulate evidence based on test data, make arguments to defend their conclusions, critically evaluate the ideas of others, and revise their designs to identify the best solution.

FIGURE 2.8. OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

Science cannot advance if scientists are unable to communicate their findings clearly and persuasively or learn about the findings of others. A major practice of science is thus to communicate ideas and the results of inquiry orally and in writing; with the use of tables, diagrams, graphs, and equations; and by engaging in extended discussions with peers. Science requires the ability to derive meaning from scientific texts such as papers, the internet, symposia, or lectures to evaluate the scientific validity of the information thus acquired and integrate that information into proposed explanations.	**Engineering** cannot produce new or improved technologies if the advantages of their designs are not communicated clearly and persuasively. Engineers need to be able to express their ideas orally and in writing; with the use of tables, graphs, drawings, or models; and by engaging in extended discussions with peers. Moreover, as with scientists, they need to be able to derive meaning from colleagues' texts, evaluate information, and apply it usefully.

Even before elementary school, children ask questions of each other and of adults about things around them, including the natural and designed world. If students develop the practices of science and engineering, they can ask better questions and improve how they define problems. Students should, for example, learn how to ask questions of each other, recognize the difference between questions and problems, and evaluate scientific questions and engineering problems from other types of questions and problems. In upper grades, the practices of asking scientific questions and defining engineering problems advance in subtle ways such as the form and function of data used in answering questions and the criteria and constraints applied to solving problems.

In the lower grades, the idea of scientific and engineering models can be introduced using pictures, diagrams, drawings, and simple physical models such as airplanes or cars. In upper grades, simulations and more sophisticated conceptual, mathematical, and computational models may be used to conduct investigations, explore changes in system components, and generate data that can be used to formulate scientific explanations or propose technological solutions.

Planning and carrying out investigations should be standard experiences in K–12 classrooms. Across the grades, students develop deeper and richer understandings and abilities as they conduct different types of investigations, use different technologies to collect data, give greater attention to the types of variables, and clarify the scientific or engineering contexts for investigations.

Both science and engineering involve the analysis and interpretation of data. In lower grades, students can begin recording and sharing observations through drawings, writing, whole numbers, and oral reports. In middle and high school, students report relationships and patterns in data, distinguish between correlation and causation, and compare and contrast independent sets of data for consistency and confirmation of an explanation or solution.

Although the practices are not necessarily sequential, the connection of these practices with the next practices—using mathematical and computational thinking—is important. Both of these sets of practices can be completed with simulated data, and it is beneficial for students to actually experience the practices of collecting, analyzing, and interpreting data while using mathematical and computational thinking.

In the early grades, students can learn to use appropriate instruments (e.g., rulers and thermometers) and their units in measurements and quantitative results to compare proposed solutions to an engineering problem. In upper grades, students can use computers to analyze data sets and express the significance of data using statistics.

Students can learn to use computers to record measurements, summarize and display data, and calculate relationships. As students progress to higher grades, their experiences in science classes should enhance what they learn in math class.

The aim for students at all grade levels is to learn how to use evidence to formulate a logically coherent explanation of phenomena and support a proposed solution for an engineering problem. The constructions of an explanation or solution should incorporate current scientific knowledge and often include a model. These practices, along with those in Figure 2.1 (p. 16), differentiate science from engineering.

In elementary grades, students might listen to two different explanations for an observation and decide which is better supported with evidence. Students might listen to other students' proposed solutions and ask for the evidence supporting the proposal. In upper grades, students should learn to identify claims; differentiate between data and evidence; and use logical reasoning in oral, written, and graphic presentations.

In elementary grades, these practices entail sharing scientific and technological information; mastering oral and written presentations; and using models, drawings, and numbers appropriately. As students progress, the practices become more complex and might include preparing reports of investigations; communicating using multiple formats; constructing arguments; and incorporating multiple lines of evidence, different models, and evaluative analysis.

CROSSCUTTING CONCEPTS

A second dimension described in the *Framework* is crosscutting concepts. These also have been discussed in an earlier NSTA article (Duschl 2012). The crosscutting concepts are summarized in Figure 2.9 (p. 20) and are similar to the unifying concepts in the 1996 *National Science Education Standards* (*NSES*). The concepts bridge disciplinary boundaries and have explanatory power across the sciences and in engineering. Crosscutting concepts provide individuals with an organizational framework that transcends disciplines and connects knowledge into a coherent world view.

FIGURE 2.9. CROSSCUTTING CONCEPTS FOR K–12 SCIENCE EDUCATION

1. ***Patterns***. Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying the patterns.
2. ***Cause and effect**: **Mechanism and explanation.*** Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships and the mechanisms by which they are mediated is a major activity of science.
3. ***Scale, proportion, and quantity***. In considering phenomena, it is critical to recognize what is relevant at different sizes, times, and energy scales and proportional relationships between different quantities as scales change.
4. ***Systems and system models***. Delimiting and defining the system under study and making a model of it are tools for developing understanding used throughout science and engineering.
5. ***Energy and matter**: **Flows, cycles, and conservation.*** Tracking energy and matter flows into, out of, and within systems helps one understand a system's behavior.
6. ***Structure and function***. The way an object is shaped or structured determines many of its properties and functions.
7. ***Stability and change***. For both designed and natural systems, conditions of stability and what controls rates of change are critical elements to consider and understand.

DISCIPLINARY CORE IDEAS

The third dimension of content for the *NGSS* is one familiar to science teachers—major ideas of the physical, life, and Earth and space science disciplines. Two other domains are included in this category: engineering, technology, and application of science and the nature of science. Figures 2.10 through 2.15 introduce the disciplinary core ideas.

FIGURE 2.10. CORE AND COMPONENT IDEAS IN THE PHYSICAL SCIENCES

Core Idea: Matter and Its Interactions

A: Structure and Properties of Matter
B: Chemical Reactions
C: Nuclear Processes

Core Idea: Motion and Stability: Forces and Interactions

A: Forces and Motion
B: Types of Interactions
C: Stability and Instability in Physical Systems

Core Idea: Energy

A: Definitions of Energy
B: Conservation of Energy and Energy Transfer
C: Relationship Between Energy and Forces
D: Energy in Chemical Processes and Everyday Life

Core Idea: Waves and Their Applications in Technologies for Information Transfer

A: Wave Properties
B: Electromagnetic Radiation
C: Information Technologies and Instrumentation

FIGURE 2.11. CORE AND COMPONENT IDEAS IN THE LIFE SCIENCES

Core Idea: From Molecules to Organisms: Structures and Processes

A: Structure and Function
B: Growth and Development of Organisms
C: Organization for Matter and Energy Flow in Organisms
D: Information Processing

Core Idea: Ecosystems: Interactions, Energy, and Dynamics

A: Interdependent Relationships in Ecosystems
B: Cycles of Matter and Energy Transfer in Ecosystems
C: Ecosystems Dynamics, Functioning, and Resilience
D: Social Interactions and Group Behavior

Core Idea: Heredity: Inheritance and Variation of Traits

A: Inheritance of Traits
B: Variation of Traits

Core Idea: Biological Evolution: Unity and Diversity

A: Evidence of Common Ancestry and Diversity
B: Natural Selection
C: Adaptation
D: Biodiversity and Humans

FIGURE 2.12. CORE AND COMPONENT IDEAS IN EARTH AND SPACE SCIENCES

Core Idea: Earth's Place in the Universe

A: The Universe and Its Stars
B: Earth and the Solar System
C: The History of Planet Earth

Core Idea: Earth's Systems

A: Earth Materials and Systems
B: Plate Tectonics and Large-Scale System Interactions
C: The Roles of Water in Earth's Surface Processes
D: Weather and Climate
E: Biogeology

Core Idea: Earth and Human Activity

A: Natural Resources
B: Natural Hazards
C: Human Impacts on Earth Systems
D: Global Climate Change

FIGURE 2.13. DEFINITIONS OF TECHNOLOGY, ENGINEERING, AND APPLICATIONS OF SCIENCE

Technology is any modification of the natural world made to fulfill human needs or desires.

Engineering is a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants.

An application of science is any use of scientific knowledge for a specific purpose, whether to do more science; design a product, process, or medical treatment; develop a new technology; or predict the impacts of human actions.

FIGURE 2.14. CORE AND COMPONENT IDEAS IN ENGINEERING, TECHNOLOGY, AND APPLICATIONS OF SCIENCE

Core Idea: Engineering Design

A: Defining and Delimiting an Engineering Problem
B: Developing Possible Solutions
C: Optimizing the Design Solution

Core Idea: Links Among Engineering, Technology, Science, and Society

A: Interdependence of Science, Engineering, and Technology
B: Influence of Engineering, Technology and Science on Society and the Natural World

FIGURE 2.15. UNDERSTANDINGS ABOUT THE NATURE OF SCIENCE

- Scientific investigations use a variety of methods.
- Scientific knowledge is based on empirical evidence.
- Scientific knowledge is open to revision in light of new evidence.
- Science models, laws, mechanisms, and theories explain natural phenomena.
- Science is a way of knowing.
- Scientific knowledge assumes an order and consistency in natural systems.
- Science is a human endeavor.
- Science addresses questions about the natural and material world.

Although not explicitly described in the *Framework*, state leaders and the public pressed for inclusion of the nature of science in the *NGSS*. Figure 2.15 summarizes the basic understandings of the nature of science in *NGSS*.

DISCIPLINARY CORE AND COMPONENT IDEAS FOR THE LIFE SCIENCES: A DEEPER DISCUSSION

In anticipation of discussions of standards particularly in Chapters 5–7, K–12 learning progressions, and examples of classroom practices, this section presents a more detailed discussion of disciplinary core ideas from the life sciences. Like earlier presentations, this one also is based on the *Framework* (NRC 2012).

From Molecules to Organisms: Structures and Processes addresses the characteristic structures of organisms. Individual organisms also accomplish specific functions to support life, growth, behavior, and reproduction. This core idea centers on the unifying principle that cells are the basic unit of life. Components of the core idea include Structure and Function, Growth and Development of Organisms, Organization for Matter and Energy Flow in Organisms, and Information Processing.

Beginning with cells as the basic structural units of life, organisms present a hierarchy of structural systems and subsystems that perform specialized functions. A central problem of biology is to develop explanations for functions based on structures, and the reciprocal—to explain the complementarity of structures and functions among an organism's systems and subsystems.

As organisms grow and develop, their anatomy and morphology (structures), processes from the cellular to organism level, and behaviors change in predictable ways. Grasping the concepts of cell division and gene expression is central to understanding the growth and development of organisms.

Organisms require matter and energy to live and grow. In most cases, the energy needed by organisms is derived from the Sun through photosynthesis. As a result of chemical changes, energy is transferred from one system of interacting molecules to another and across different organizational levels from cells to ecosystems.

Organisms have mechanisms to detect, process, and use information about the environment. That information contributes to an organism's survival, growth, and reproduction.

Ecosystems: Interactions, Energy, and Dynamics include organisms' interactions with each other and their physical environment. Biologists develop explanations for how organisms obtain resources, how they change their environment, how changing environmental factors affect organisms and ecosystems, how social interactions and group behavior play out within and between species, and how these factors all combine to determine ecosystem functioning. This core idea includes Interdependent Relationships in Ecosystems, Cycles of Matter and Energy Transfer in Ecosystems, Ecosystem Dynamics, Functioning, and Resilience, and Social Interactions and Group Behavior.

An ecosystem includes both biological communities (biotic) and physical (abiotic) components of the environment. Ecosystems continually change due to the interdependence of biotic and the abiotic elements of the environment. As organisms seek matter and energy to sustain life, the interactions may result in food webs.

Interactions among organisms and the physical environment influence the cycling of matter and flow of energy in ecosystems. Plants require light energy for photosynthesis—a chemical reaction that produces plant matter from air and water. As animals meet their need for food, the chemical elements that make up organisms are combined and recombined as those chemicals' elements pass through food webs. The cycling of matter and flow of energy through ecosystems conserve matter and energy through the many changes.

Dynamics of ecosystems result from changes in populations of organisms through time and changes in physical environments. The dynamics of ecosystems result in shifts in the diversity and numbers of organisms, the survival or extinction of species, the migration of species, and the evolution of new species. Changes in ecosystems result from natural processes and human activity. The resilience of an ecosystem is a function of greater or lesser biodiversity.

Organisms ranging from unicellular slime molds to humans demonstrate group behavior. Group behavior can be explained by its survival value for individuals.

Heredity: Inheritance and Variation of Traits focuses on the flow of genetic information between generations. This core idea explains the mechanisms of genetic inheritance and describes the environmental and genetic causes of gene mutation and the alteration of gene expression. Inheritance of Traits and Variation of Traits are the components of this core idea.

Heredity refers to the processes by which characteristics of a species are passed from one generation to the next. Heredity explains why offspring look like but are not identical to parents.

Chromosomes carry the genetic information for a species' characteristics. Each chromosome consists of a single DNA molecule, and each gene is a particular segment of DNA. DNA molecules consist of four building blocks called nucleotides that form a linked sequence. The sequence of nucleotides constitutes a gene's information. Through cellular processes, the genetic information forms proteins that build on organism's characteristics.

Genetic and environmental factors produce variations of traits within a species. A variation in traits can influence an organism's development, appearance, behavior, and ability to produce offspring. The distribution of variations of traits in a population is an important factor in biological evolution.

Biological Evolution: Unity and Diversity explores "changes in the traits of populations of organisms over time" to explain species' unity and diversity. Biological evolution is supported by extensive scientific evidence ranging from the fossil record to genetic relationships among species. This core idea includes Evidence of Common Ancestry and Diversity, Natural Selection, Adaptation, and Biodiversity and Humans.

Biological evolution results from changing environmental factors and the subsequent selection from among genetic variations in a population that, across generations, changes the distribution of those characteristics in that population.

Common ancestry and diversity are supported by multiple lines of empirical evidence, including the fossil record, comparative anatomy and embryology, similarities of cellular processes and structures, and comparisons of DNA sequences between species. Recent advances in molecular biology have provided new empirical evidence supporting prior explanations for changes in the fossil record and links between living and extinct species.

As environments change, organisms with variations of some traits may be more likely than others to survive and reproduce. Genetic variation in a species makes this process of natural selection possible. In time, natural selection results in changes in the distribution of certain traits—that is, selection leads to an increase in the number of organisms in a population with certain inherited traits and a decrease in the number of organisms with other traits.

Natural selection is the mechanism by which species adapt to changes in an environment's resources or the physical limits and biological challenges it imposes. In the course of many generations, adaptation can result in the formation of new species. If a population cannot adapt due to a lack of traits that contribute to survival and reproduction, the species may become extinct.

Biodiversity is the multiplicity of genes, species, and ecosystems. It provides humans with renewable resources and benefits such as ecosystem services. Biological resources must be used within sustainable limits, or there will be detrimental consequences such as ecosystem degradation, species extinction, and less of ecosystem services.

The four core ideas for the life sciences have a long history and solid foundation as the basis for the life sciences in school programs (Hurd 1961; Bybee and Bloom 2008; BSCS 1993). These core ideas extend and elaborate on those established K–12 science education standards: *National Science Education Standards* (NRC 1996) and *Benchmarks for Science Literacy* (AAAS 1993). The ideas also incorporate the *Science College Board Standards for College Success* (College Board 2009), and the ideas are consistent with frameworks for national and international assessments.

FROM THE *FRAMEWORK* TO *NGSS*

The NRC's *Framework* provides guidance for developing standards through 13 recommendations designed to ensure fidelity to the *Framework* and serve as direction for the development of standards. For this discussion, the following summarizes the NRC recommendations in the *Framework* for standards development.

The standards should

- Set rigorous goals for all students.
- Be scientifically accurate.
- Be limited in number.
- Emphasize all three dimensions.
- Include performance expectations that integrate the three dimensions.
- Be informed by research on learning and teaching.
- Meet the diverse needs of students and states.
- Have potential for a coherent progression across grades and within grades.
- Be explicit about resources, time, and teacher expertise.
- Align with other K–12 subjects, especially the *Common Core State Standards*.
- Take into account diversity and equity. (NRC 2012, pp. 297–307)

Given the criteria and constraints for developing life science standards, I co-chaired a working group of biology teachers and science educators who developed standards for the four unifying concepts and component ideas. Tables 2.1 through 2.3 (pp. 26–30) are examples of standards and the critical elements of standards for elementary, middle, and high school life sciences, respectively.

TABLE 2.1. EXAMPLE OF A PERFORMANCE EXPECTATION FOR ELEMENTARY SCHOOL LIFE SCIENCE WITH SUPPORTING CONTENT FROM THE FOUNDATION BOX AND THE CONNECTIONS BOX

3-LS4 Biological Evolution: Unity and Diversity

3-LS4 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

3-LS4-1. Analyze and interpret data from fossils to provide evidence of the organisms and the environments in which they lived long ago. [Clarification Statement: Examples of data could include type, size, and distributions of fossil organisms. Examples of fossils and environments could include marine fossils found on dry land, tropical plant fossils found in Arctic areas, and fossils of extinct organisms.] [Assessment Boundary: Assessment does not include identification of specific fossils or present plants and animals. Assessment is limited to major fossil types and relative ages.]

3-LS4-2. Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving, finding mates, and reproducing. [Clarification Statement: Examples of cause and effect relationships could be plants that have larger thorns than other plants may be less likely to be eaten by predators; and, animals that have better camouflage coloration than other animals may be more likely to survive and therefore more likely to leave offspring.]

3-LS4-3. Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all. [Clarification Statement: Examples of evidence could include needs and characteristics of the organisms and habitats involved. The organisms and their habitat make up a system in which the parts depend on each other.]

3-LS4-4. Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.* [Clarification Statement: Examples of environmental changes could include changes in land characteristics, water distribution, temperature, food, and other organisms.] [Assessment Boundary: Assessment is limited to a single environmental change. Assessment does not include the greenhouse effect or climate change.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data Analyzing data in 3–5 builds on K–2 experiences and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. When possible and feasible, digital tools should be used. ▪ Analyze and interpret data to make sense of phenomena using logical reasoning. (3-LS4-1) **Constructing Explanations and Designing Solutions** Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems. ▪ Use evidence (e.g., observations, patterns) to construct an explanation. (3-LS4-2) **Engaging in Argument from Evidence** Engaging in argument from evidence in 3–5 builds on K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s). ▪ Construct an argument with evidence. (3-LS4-3) ▪ Make a claim about the merit of a solution to a problem by citing relevant evidence about how it meets the criteria and constraints of the problem. (3-LS4-4)	**LS2.C: Ecosystem Dynamics, Functioning, and Resilience** ▪ When the environment changes in ways that affect a place's physical characteristics, temperature, or availability of resources, some organisms survive and reproduce, others move to new locations, yet others move into the transformed environment, and some die. *(secondary to 3-LS4-4)* **LS4.A: Evidence of Common Ancestry and Diversity** ▪ Some kinds of plants and animals that once lived on Earth are no longer found anywhere. *(Note: moved from K-2)* (3-LS4-1) ▪ Fossils provide evidence about the types of organisms that lived long ago and also about the nature of their environments. (3-LS4-1) **LS4.B: Natural Selection** ▪ Sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates, and reproducing. (3-LS4-2) **LS4.C: Adaptation** ▪ For any particular environment, some kinds of organisms survive well, some survive less well, and some cannot survive at all. (3-LS4-3) **LS4.D: Biodiversity and Humans** ▪ Populations live in a variety of habitats, and change in those habitats affects the organisms living there. (3-LS4-4)	**Cause and Effect** ▪ Cause and effect relationships are routinely identified and used to explain change. (3-LS4-2),(3-LS4-3) **Scale, Proportion, and Quantity** ▪ Observable phenomena exist from very short to very long time periods. (3-LS4-1) **Systems and System Models** ▪ A system can be described in terms of its components and their interactions. (3-LS4-4) -- ***Connections to Engineering, Technology, and Applications of Science*** **Interdependence of Science, Engineering, and Technology** ▪ Knowledge of relevant scientific concepts and research findings is important in engineering. (3-LS4-3) -- ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** ▪ Science assumes consistent patterns in natural systems. (3-LS4-1)

Connections to other DCIs in third grade: **3.LS4.C** (3-LS4-2); **3.ESS2.D** (3-LS4-3); **3.ESS3.B** (3-LS4-4)

Articulation of DCIs across grade-levels: **K.ESS3.A** (3-LS4-3)(3-LS4-4); **K.ETS1.A** (3-LS4-4); **1.LS3.A** (3-LS4-2); **2.LS2.A** (3-LS4-3),(3-LS4-4); **2.LS4.D** (3-LS4-3),(3-LS4-4); **4.ESS1.C** (3-LS4-1); **4.ESS3.B** (3-LS4-4); **4.ETS1.A** (3-LS4-4); **MS.LS2.A** (3-LS4-1),(3-LS4-2),(3-LS4-3),(3-LS4-4); **MS.LS2.C** (3-LS4-4); **MS.LS3.B** (3-LS4-2); **MS.LS4.A** (3-LS4-1); **MS.LS4.B** (3-LS4-2),(3-LS4-3); **MS.LS4.C** (3-LS4-3),(3-LS4-4); **MS.ESS1.C** (3-LS4-1),(3-LS4-3),(3-LS4-4); **MS.ESS2.B** (3-LS4-1); **MS.ESS3.C** (3-LS4-4)

Common Core State Standards Connections:

ELA/Literacy –

RI.3.1 Ask and answer questions to demonstrate understanding of a text, referring explicitly to the text as the basis for the answers. *(3-LS4-1),(3-LS4-2),(3-LS4-3) (3-LS4-4)*

RI.3.2 Determine the main idea of a text; recount the key details and explain how they support the main idea. *(3-LS4-1),(3-LS4-2),(3-LS4-3),(3LS4-4)*

RI.3.3 Describe the relationship between a series of historical events, scientific ideas or concepts, or steps in technical procedures in a text, using language that pertains to time, sequence, and cause/effect. *(3-LS4-1),(3-LS4-2),(3-LS4-3),(3-LS4-4)*

W.3.1 Write opinion pieces on topics or texts, supporting a point of view with reasons. *(3-LS4-1)*,(3-LS4-3),*(3-LS4-4)*

W.3.2 Write informative/explanatory texts to examine a topic and convey ideas and information clearly. *(3-LS4-1)*,(3-LS4-2),*(3-LS4-3),(3-LS4-4)*

W.3.9 Recall information from experiences or gather information from print and digital sources; take brief notes on sources and sort evidence into provided categories. (3-LS4-1)

SL.3.4 Report on a topic or text, tell a story, or recount an experience with appropriate facts and relevant, descriptive details, speaking clearly at an understandable pace. *(3-LS4-2),(3-LS4-3),(3-LS4-4)*

Mathematics –

MP.2 Reason abstractly and quantitatively. *(3-LS4-1),(3-LS4-2),(3-LS4-3),(3-LS4-4)*

MP.4 Model with mathematics. *(3-LS4-1),(3-LS4-2),(3-LS4-3),(3-LS4-4)*

MP.5 Use appropriate tools strategically. *(3-LS4-1)*

3.MD.B.3 Draw a scaled picture graph and a scaled bar graph to represent a data set with several categories. Solve one- and two-step "how many more" and "how many less" problems using information presented in scaled bar graphs. *(3-LS4-2),(3-LS4-3)*

3.MD.B.4 Generate measurement data by measuring lengths using rulers marked with halves and fourths of an inch. Show the data by making a line plot, where the horizontal scale is marked off in appropriate units—whole numbers, halves, or quarters. *(3-LS4-1)*

TABLE 2.2. EXAMPLE OF A PERFORMANCE EXPECTATION FOR MIDDLE SCHOOL LIFE SCIENCE WITH SUPPORTING CONTENT FROM THE FOUNDATION BOX AND THE CONNECTIONS BOX

MS-LS4 Biological Evolution: Unity and Diversity

MS-LS4 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past. [Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [Assessment Boundary: Assessment does not include the names of individual species or geological eras in the fossil record.]

MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships. [Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.]

MS-LS4-3. Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy. [Clarification Statement: Emphasis is on inferring general patterns of relatedness among embryos of different organisms by comparing the macroscopic appearance of diagrams or pictures.] [Assessment Boundary: Assessment of comparisons is limited to gross appearance of anatomical structures in embryological development.]

MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. [Clarification Statement: Emphasis is on using simple probability statements and proportional reasoning to construct explanations.]

MS-LS4-5. Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms. [Clarification Statement: Emphasis is on synthesizing information from reliable sources about the influence of humans on genetic outcomes in artificial selection (such as genetic modification, animal husbandry, gene therapy); and, on the impacts these technologies have on society as well as the technologies leading to these scientific discoveries.]

MS-LS4-6. Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time. [Clarification Statement: Emphasis is on using mathematical models, probability statements, and proportional reasoning to support explanations of trends in changes to populations over time.] [Assessment Boundary: Assessment does not include Hardy Weinberg calculations.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.
- Analyze displays of data to identify linear and nonlinear relationships. (MS-LS4-3)
- Analyze and interpret data to determine similarities and differences in findings. (MS-LS4-1)

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 6–8 builds on K–5 experiences and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments.
- Use mathematical representations to support scientific conclusions and design solutions. (MS-LS4-6)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.
- Apply scientific ideas to construct an explanation for real-world phenomena, examples, or events. (MS-LS4-2)
- Construct an explanation that includes qualitative or quantitative relationships between variables that describe phenomena. (MS-LS4-4)

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 6–8 builds on K–5 experiences and progresses to evaluating the merit and validity of ideas and methods.
- Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence. (MS-LS4-5)

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence
- Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-LS4-1)

Disciplinary Core Ideas

LS4.A: Evidence of Common Ancestry and Diversity
- The collection of fossils and their placement in chronological order (e.g., through the location of the sedimentary layers in which they are found or through radioactive dating) is known as the fossil record. It documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth. (MS-LS4-1)
- Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record, enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent. (MS-LS4-2)
- Comparison of the embryological development of different species also reveals similarities that show relationships not evident in the fully-formed anatomy. (MS-LS4-3)

LS4.B: Natural Selection
- Natural selection leads to the predominance of certain traits in a population, and the suppression of others. (MS-LS4-4)
- In *artificial* selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring. (MS-LS4-5)

LS4.C: Adaptation
- Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes. (MS-LS4-6)

Crosscutting Concepts

Patterns
- Patterns can be used to identify cause and effect relationships. (MS-LS4-2)
- Graphs, charts, and images can be used to identify patterns in data. (MS-LS4-1),(MS-LS4-3)

Cause and Effect
- Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability. (MS-LS4-4),(MS-LS4-5),(MS-LS4-6)

Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology
- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. (MS-LS4-5)

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. (MS-LS4-1),(MS-LS4-2)

Science Addresses Questions About the Natural and Material World
- Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS4-5)

Connections to other DCIs in this grade-band: **MS.LS2.A** (MS-LS4-4),(MS-LS4-6); **MS.LS2.C** (MS-LS4-6); **MS.LS3.A** (MS-LS4-2),(MS-LS4-4); **MS.LS3.B** (MS-LS4-2),(MS-LS4-4),(MS-LS4-6); **MS.ESS1.C** (MS-LS4-1),(MS-LS4-2),(MS-LS4-6); **MS.ESS2.B** (MS-LS4-1)

Articulation across grade-bands: **3.LS3.B** (MS-LS4-4); **3.LS4.A** (MS-LS4-1),(MS-LS4-2); **3. LS4.B** (MS-LS4-4); **3.LS4.C** (MS-LS4-6); **HS.LS2.A** (MS-LS4-4),(MS-LS4-6); **HS.LS2.C** (MS-LS4-6); **HS.LS3.B** (MS-LS4-4),(MS-LS4-5),(MS-LS4-6); **HS.LS4.A** (MS-LS4-1),(MS-LS4-2),(MS-LS4-3); **HS.LS4.B** (MS-LS4-4),(MS-LS4-6); **HS.LS4.C** (MS-LS4-4),(MS-LS4-

Table 2.2. (*continued*)

MS-LS4 Biological Evolution: Unity and Diversity

5),(MS-LS4-6); **HS.ESS1.C** (MS-LS4-1),(MS-LS4-2)	
Common Core State Standards Connections:	
ELA/Literacy –	
RST.6-8.1	Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions *(MS-LS4-1)*,(MS-LS4-2),*(MS-LS4-3),(MS-LS4-4)*,(MS-LS4-5)
RST.6-8.7	Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-LS4-1),(MS-LS4-3)
RST.6-8.9	Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. *(MS-LS4-3),(MS-LS4-4)*
WHST.6-8.2	Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS4-2),(MS-LS4-4)
WHST.6-8.8	Gather relevant information from multiple print and digital sources; assess the credibility of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and providing basic bibliographic information for sources. *(MS-LS4-5)*
WHST.6-8.9	Draw evidence from informational texts to support analysis, reflection, and research. (MS-LS4-2),(MS-LS4-4)
SL.8.1	Engage effectively in a range of collaborative discussions (one-on-one, in groups, teacher-led) with diverse partners on grade 6 topics, texts, and issues, building on others' ideas and expressing their own clearly. *(MS-LS4-2),(MS-LS4-4)*
SL.8.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. *(MS-LS4-2),(MS-LS4-4)*
Mathematics –	
MP.4	Model with mathematics. (MS-LS4-6)
6.RP.A.1	Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. *(MS-LS4-4),(MS-LS4-6)*
6.SP.B.5	Summarize numerical data sets in relation to their context. *(MS-LS4-4),(MS-LS4-6)*
6.EE.B.6	Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set. *(MS-LS4-1),(MS-LS4-2)*
7.RP.A.2	Recognize and represent proportional relationships between quantities. *(MS-LS4-4),(MS-LS4-6)*

TABLE 2.3. EXAMPLE OF TWO PERFORMANCE EXPECTATIONS FOR HIGH SCHOOL LIFE SCIENCE WITH SUPPORTING CONTENT FROM THE FOUNDATION BOX AND THE CONNECTIONS BOX

HS-LS4 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

HS-LS4-1. **Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.** [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]

HS-LS4-2. **Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species du to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.** [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limite resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.]

HS-LS4-3. **Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.** [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.]

HS-LS4-4. **Construct an explanation based on evidence for how natural selection leads to adaptation of populations.** [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

HS-LS4-5. **Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.** [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

HS-LS4-6. **Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*** [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organism for multiple species.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. (HS-LS4-3)

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create or revise a simulation of a phenomenon, designed device, process, or system. (HS-LS4-6)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS4-2),(HS-LS4-4)

Engaging in Argument from Evidence
Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current or historical episodes in science.

- Evaluate the evidence behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS4-5)

Obtaining, Evaluating, and Communicating Information

Disciplinary Core Ideas

LS4.A: Evidence of Common Ancestry and Diversity

- Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence. (HS-LS4-1)

LS4.B: Natural Selection

- Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. (HS-LS4-2),(HS-LS4-3)
- The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. (HS-LS4-3)

LS4.C: Adaptation

- Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. (HS-LS4-2)
- Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. (HS-LS4-3),(HS-LS4-4)
- Adaptation also means that the distribution of traits in a population can change when conditions change. (HS-LS4-3)
- Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species.

Crosscutting Concepts

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena (HS-LS4-1),(HS-LS4-3)

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS4-2),(HS-LS4-4),(HS-LS4-5),(HS-LS4-6)

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. (HS LS4-1),(HS-LS4-4)

Table 2.3. (*continued*)

HS-LS4 Biological Evolution: Unity and Diversity

builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. ▪ Communicate scientific information (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-LS4-1) --- ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ▪ A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. (HS-LS4-1)	▪ Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost. (HS-LS4-5) **LS4.D: Biodiversity and Humans** ▪ Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (HS-LS4-6) *(Note: This Disciplinary Core Idea is also addressed by HS-LS2-7.)* **ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary to HS-LS4-6)* ▪ Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. *(secondary to HS-LS4-6)*	

Connections to other DCIs in this grade-band: **HS.LS2.A** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4),(HS-LS4-5); **HS.LS2.D** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4),(HS-LS4-5); **HS.LS3.A** (HS-LS4-1); **HS.LS3.B** (HS-LS4-1),(HS-LS4-2) (HS-LS4-3),(HS-LS4-5); **HS.ESS1.C** (HS-LS4-1); **HS.ESS2.D** (HS-LS4-6); **HS.ESS2.E** (HS-LS4-2),(HS-LS4-5),(HS-LS4-6); **HS.ESS3.A** (HS-LS4-2),(HS-LS4-5),(HS-LS4-6); **HS.ESS3.C** (HS-LS4-6); **HS.ESS3.D** (HS-LS4-6)

Articulation across grade-bands: **MS.LS2.A** (HS-LS4-2),(HS-LS4-3),(HS-LS4-5); **MS.LS2.C** (HS-LS4-5),(HS-LS4-6); **MS.LS3.A** (HS-LS4-1); **MS.LS3.B** (HS-LS4-1),(HS-LS4-2),(HS-LS4-3); **MS.LS4.A** (HS-LS4-1); **MS.LS4.B** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4); **MS.LS4.C** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4),(HS-LS4-5); **MS.ESS1.C** (HS-LS4-1); **MS.ESS3.C** (HS-LS4-5),(HS-LS4-6)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-LS4-1)*,(HS-LS4-2),*(HS-LS4-3)*,(HS-LS4-4)
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS4-5)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-LS4-1)*,(HS-LS4-2),*(HS-LS4-3)*,(HS-LS4-4)
WHST.9-12.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. *(HS-LS4-6)*
WHST.9-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-LS4-6)
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *(HS-LS4-1)*,(HS-LS4-2),*(HS-LS4-3)*,(HS-LS4-4),(HS-LS4-5)
SL.11-12.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. *(HS-LS4-1)*,*(HS-LS4-2)*

Mathematics –

MP.2	Reason abstractly and quantitatively. *(HS-LS4-1)*,(HS-LS4-2),(HS-LS4-3),*(HS-LS4-4)*,*(HS-LS4-5)*
MP.4	Model with mathematics. *(HS-LS4-2)*

The architecture seen in Tables 2.1 through 2.3 requires some clarification. The title Biological Evolution: Unity and Diversity represents a progression for elementary, middle, and high school life sciences. The figures include the performance expectations in the top portion, listed as numbers 1, 2, and so on in the three figures. The performance expectations are formed by combining a science and engineering practice, disciplinary core idea, and crosscutting concept.

Immediately beneath the standard, you see the foundation box consisting of three sections, one each for science and engineering practices, disciplinary core ideas, and crosscutting concepts. These three columns describe content from the NRC *Framework* that was incorporated into the performance expectations and serve to clarify the performance expectations in content. You should note the relationship between numbers before the performance expectations and at the end of statements in the foundation box (for example, MS-LS4-1). Descriptions in the foundation box answer the following questions:

- What are the essential knowledge and abilities of the performance expectations?
- What are the specific details of the practices, disciplinary core ideas, and crosscutting concepts that students should know and be able to do?
- What should be emphasized in the science curriculum and classroom instruction?

The performance expectations are learning outcomes, not instructional activities, and they are the basis for assessments. One should note that along with content in the foundation box, they may be the point of departure for backward design of curriculum and instruction (Wiggins and McTighe 2005).

The three examples displayed in Tables 2.1 through 2.3 also serve the purpose of demonstrating a learning progression across the grades. Although elementary students do not learn the mechanisms of natural selection, for example, they learn about the evidence the fossils provide about ancient organisms and environments and the survival advantages of variations among individual organisms, concepts fundamental to biological evolution developed in greater detail in the middle and high school science program. Other standards, such as interdependent relations in ecosystems, also provide the conceptual foundation for students' later understanding biological evolution.

FROM STANDARDS TO CURRICULUM AND INSTRUCTION

From the late 1980s to the first decade of the 21st century, teachers of K–12 science and the larger science education community have witnessed an era of standards-based reform. Basically, the idea is to develop clear, comprehensive, and challenging goals for student learning. Review, for example, the aforementioned guidelines for developing standards. Beyond learning goals, the implicit assumption was that standards would be used to make other components of the education system—curriculum, instruction, assessments, and the professional development of teachers—more clearly aligned. Common sense supports this view.

In 2001, the Elementary and Secondary Education Act (ESEA) legislation No Child Left Behind established assessment as an emphasis in the education system. This shift in emphasis has had a significant influence on the education system's components. Assessment and accountability have been primary concerns of educators, and curriculum and instruction have been secondary, at best. We have gone directly from standards to assessments without addressing curriculum and instruction as the teaching and learning connection between standards and assessments.

Relative to the *NGSS*, I am particularly concerned about questions science teachers frequently ask: Where are the curriculum materials that will help me implement the standards in my classroom? And will assessments change? These are both critical questions. There are several initiatives relative to assessment or *NGSS*, but few discussions of instructional materials that align with the new standards.

I cannot emphasize enough the need for clear and coherent curriculum and instruction that connect the standards and assessments. Curriculum materials will be the missing link if they are not developed and implemented. The absence of a curriculum based on the standards will be a major failure in this era of standards-based reform and assessment-dominated results. When science teachers at all levels K–12 ask, "Where are the materials that help me teach to the standards?" the larger education system must have a concrete answer.

Conclusion

The *NGSS* likely will influence K–12 science teaching for a decade, or longer if the history of science education standards from the 1990s has any value in anticipating the future. This chapter introduces the *NGSS* and uses the life sciences as the context for deeper discussions of important content, some challenges, and several opportunities faced by K–12 teachers of science.

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CHAPTER 3

NGSS: 10 Frequently Answered Questions

National efforts to develop standards inevitably have political overtones that can result in misunderstandings about standards in general, and the *Next Generation Science Standards* (*NGSS*) in this case. The following questions about *NGSS* arise as people learn about these standards. The questions have been asked and answered on a variety of occasions. I think the questions are comprehensive and the answers important for those leaders who are responsible for implementing the standards.

Question 1: What Is *A Framework for K–12 Science Education* (NRC 2012), and How Is It Related to the *NGSS*?

The National Research Council's (NRC) 2012 publication *A Framework for K–12 Science Education* presents a vision of what the standards will be and the effect those standards should have on science education.

The *Framework* provides a foundation for the new standards and changes in K–12 science programs. That foundation has three essential dimensions: science and engineering practices, crosscutting concepts, and core ideas in science disciplines.

The *Framework* and *NGSS* are related through (1) the description of content (i.e., science and engineering practices, crosscutting concepts, and disciplinary core ideas) and (2) the guidance for development of standards for science education. Achieve, Inc., and the teams developing the standards had to maintain the content and guidelines for standards.

Question 2: How Do These Standards Differ From the *National Science Education Standards* (NRC 1996) or Those Described in *Benchmarks for Science Literacy* (AAAS 1993)?

The *National Science Education Standards* (*NSES*) were published in 1996. Prior to that, the AAAS *Benchmarks for Science Literacy* were published in 1993. Both documents have influenced state and local science education for almost two decades. During that time, we have made progress in science and technology and advances in our understanding of how people learn in general and how students learn the STEM disciplines in particular.

Figures 3.1 through 3.3 (pp. 36–37) describe some of the similarities and differences between the *NSES* and the *NGSS*.

FIGURE 3.1. COMPARISON OF KEY CATEGORIES OF CONTENT IN *NSES* AND *NGSS*

National Science Education Standards (*NSES*; NRC 1996)	*Next Generation Science Standards* (*NGSS*; Achieve Inc. 2013)
• Science as Inquiry ▪ Abilities necessary to do scientific inquiry ▪ Understanding about scientific inquiry	• Science and Engineering Practices
• Physical Science	• Physical Science
• Life Science	• Life Science
• Earth and Space Science	• Earth and Space Science
• Science and Technology	• Engineering, Technology, and Applications of Science
• Science in Personal and Social Perspectives	
• History and Nature of Science	• Nature of Science
• Unifying Concepts and Processes	• Crosscutting Concepts

FIGURE 3.2. COMPARISON OF ORIENTATION OF *NSES* AND *NGSS*

National Science Education Standards (*NSES*; NRC 1996)	*Next Generation Science Standards* (*NGSS*; Achieve Inc. 2013)
• Standards as Descriptions of Content • Standards as Separate Disciplines of Content	• Standards as Descriptions of Performance Expectations • Standards as Integration of Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas

FIGURE 3.3. ADDITIONAL DISCUSSIONS IN *NSES* AND *NGSS*

National Science Education Standards (*NSES*; NRC 1996)	*Next Generation Science Standards* (*NGSS*; Achieve 2013)
• Science teaching standards • Standards for professional development of teachers of science • Program standards • System standards	• College and career readiness • All standards, all students • Science and engineering practices • Crosscutting concepts • Nature of science • Engineering design, technology, and the applications of science • Disciplinary core idea progression • Model course mapping in middle school and high school • Connections to *Common Core State Standards*

Several innovations for *NGSS* are worth noting. First, there is a shift from standards as statements of content to standards as descriptions of performance expectations. This shift gives great emphasis to assessment for the *NGSS*. My concern is that performance expectations describe policies for assessment and generally ignore designs for curriculum and instruction.

Second, the three dimensions—practices, crosscutting concepts, and disciplinary core ideas—are integrated into the performance expectations. One should note that content in the foundation boxes is similar to the descriptions of content in *NSES*. This means that teaching and assessments should recognize all three dimensions, not just the disciplinary core ideas. The integrations of three dimensions do present a significant challenge for curriculum, instruction, and assessment.

Third, engineering and the nature of science also are integrated into the performance expectations. Finally, the teams developing standards have endeavored to design learning progressions from elementary school through middle and high school.

QUESTION 3: WHAT HAS BEEN THE GUIDING FORCE IN THE DEVELOPMENT OF THE *NGSS*?

Development of the *NGSS* was a multifaceted process influenced by several forces. The first force was *A Framework for K–12 Science Education*. As addressed in the prior question, the *Framework* describes the content and guidelines for the standards.

Second, the National Science Teachers Association (NSTA) and the American Association for the Advancement of Science (AAAS) were partners with Achieve, and both organizations completed focused reviews throughout the development process.

Third, early in the development process, 26 states applied to participate as lead states. As part of the application, these states agreed to "seriously consider adoption" of the standards. The lead states had multiple stakeholder groups that provided feedback at critical points in the development of standards. The *NGSS* rightfully carry the subtitle "By States, for States" as a result of the feedback and collaboration with the lead states.

Fourth, the writing team of 40 individuals—including K–12 science teachers, science coordinators, state science supervisors, scientists, engineers, and educators—provided direction in the development of the *NGSS*.

Fifth, there were two public reviews of draft standards. These reviews resulted in thousands of specific comments from scientific organizations, business and industry groups, and individual citizens. These reviews resulted in significant revisions and improvement of the standards.

Finally, some states and local districts (including non-lead states) use the final *NGSS* public draft as the basis for public review, as required by their adoption process.

QUESTION 4: HOW DO THE *NGSS* ALIGN WITH INTERNATIONAL STANDARDS?

Prior to work on the *NGSS*, Achieve completed a study of ten countries' science standards to determine their overall emphases and the expectations they have for all students (for grade spans 1–6 and 7–10), as well as emphases in biology, chemistry, physics, and Earth and space science courses in upper secondary grades. The comparison countries included those whose students performed well on the Programme for International Student Assessment (PISA) or the Trends in International Math and Science Study (TIMSS), such as Ontario (Canada), Chinese Taipei, Great Britain, Finland, Hong Kong, Hungary, Ireland, Japan, Singapore, and South Korea. (To be accurate, Ontario is a province of Canada, Hong Kong is a special administrative unit of China, and Taipei is the provincial capital of the Republic of China.)

The quantitative analysis enabled Achieve to detect patterns of emphases in major categories of knowledge and performances. Major findings for grades 1–10 were as follows:

- Seven of 10 countries require general science for all students through grade 10, prior to students taking discipline-specific courses.
- Physical science (chemistry and physics taken together) receives the most attention, biology receives somewhat less attention, and Earth and space science much less.
- Crosscutting content (such as the nature of science and engineering) and the interactions of science, technology and society, and environmental sustainability also receive significant attention.

Achieve's qualitative analysis revealed exemplary features such as the use of an overarching conceptual framework, multiple examples to clarify the level of rigor expected and connect concepts with applications of science, concrete links between standards and assessments, and development of inquiry and design processes in parallel to facilitate students engaging in both science and engineering practices.

QUESTION 5: WILL THE *NGSS* HELP PREPARE STUDENTS FOR COLLEGE AND CAREER?

Helping students prepare for STEM careers has two dimensions: first, the general "career readiness" and technical needs of a 21st-century workforce, and second, the "pipeline" issue of students, particularly women and minorities, going into STEM research and development. Experiences with science and engineering practices will certainly contribute to both college and career preparedness for students. In addition, school programs can complement those practices with 21st-century skills such as self-management and communication.

The *NGSS* describe the content and practices needed to ensure that students will be college and career ready. I think college and career readiness as a general goal is appropriate for the K–12 science standards. In this era, education has witnessed business and industry leaders demand improved STEM education. That said, K–12 STEM education should not have a specific goal of providing job training. It should be a rigorous general education that prepares students for the next level of education, whether that is university, community college, or on-the-job apprenticeship and training.

Whether concern is for a technical workforce or future scientists and engineers, if implemented through curriculum and instruction, the *NGSS* will contribute to many expressed needs of business and industry. This perspective leaves K–12 curriculum and instruction and the professional development of science teachers as critical factors in future judgments about the impact of *NGSS*. Additionally, the science and engineering practices contribute to preparation of the STEM workforce and provide future citizens with fundamental knowledge living in a world increasingly influenced by science, technology, engineering, and mathematics. Finally, I encourage the reader to review the discussion on college and career readiness in *NGSS.*

QUESTION 6: WHY ARE THE *NGSS* IMPORTANT?

Since publication of the *NSES* (NRC 1996), there have been numerous forces for education change. Business and industry have set goals for a 21st-century workforce, policy makers have identified economic goals, scientists have made the case for addressing climate change, and educators have advanced our understanding about how students learn, to name a few of the factors underlying the need to improve science education. Now the *NGSS* are the basis for that improvement.

National standards for science education have the power to influence key components within the education system. They do, for example, imply reform of the science curriculum, teacher development, and assessments.

While development of the *NSES* in the 1990s had a significant amount of review and feedback (i.e., report reviews by the NRC), *NGSS* development and review has involved key organizations such as NSTA and representative teams from 26 lead states that provided feedback throughout the process. In addition, there have been two public reviews with subsequent revisions of draft standards. This extensive and transparent process of development was unprecedented and has resulted in significant support for *NGSS* in the science education community.

The phase after development and release of *NGSS* implies professional development and changes in teachers' knowledge and skills and applications of those changes to engage student learning and achievement. The potential for many states to adopt the *NGSS* contributes to greater collaboration and focus related to these efforts. These are the reasons *NGSS* is important.

QUESTION 7: WHY USE THE TERM *PRACTICES*? WHY NOT CONTINUE USING *SCIENTIFIC INQUIRY*?

These are reasonable questions. A brief history will provide the context for my answer. One major innovation in the 1960s reform movement was the introduction of the *processes* of science as a replacement for the *methods* of science. Discussing the processes of science was supposed to shift the emphasis from students' memorizing five steps in the scientific method to learning specific and fundamental processes such as observing, measuring, inferring, and predicting. To complement this new emphasis on science processes, the reformed instructional materials incorporated activities, laboratories, and investigations that gave students opportunities to learn the processes of science while developing an understanding of the conceptual structure of science disciplines. Many classrooms still have posters displaying "the scientific method," and it is 50 years later!

During the period 1960–1990, interest and support grew for *scientific inquiry* as an approach to science teaching that emphasized learning science concepts and using the skills and abilities of inquiry to learn those concepts. This change toward scientific inquiry was expressed by leaders such as Joseph Schwab and Paul Brandwein and publications such as *Science for All Americans* (Rutherford and Ahlgren 1989). In the 1990s, scientific inquiry was fundamental to the *Benchmarks for Science Literacy* (AAAS 1993) and the *National Science Education Standards* (NRC 1996). Along with *Inquiry and the National Science Education Standards* (NRC 2000), these two publications had a significant influence on state standards and the place of inquiry in school science programs. Scientific inquiry expanded and improved the earlier processes of science and provided richer understanding of science, a set of cognitive abilities for students, and more effective teaching strategies. One should note that the reforms toward the *processes of science* and *scientific inquiry* did result in greater emphasis on the use of activities and investigations as teaching strategies to learn science concepts.

During the more than 15 years since the release of the *NSES*, researchers have advanced our knowledge about how students learn science (Bybee 2002; Donovan and Bransford 2005) and the way science functions. Advances in these and other areas have been synthesized in *Taking Science to School* (Duschl, Schweingruber, and Shouse 2007) and *Ready, Set, Science!* (Michaels, Shouse, and Schweingruber 2008). These two publications had a significant influence on the NRC's *Framework*.

Taking Science to School describes four proficiencies that link the content and practices of science. Students who are proficient in science

- know, use, and interpret scientific explanations of the natural world;
- generate and evaluate scientific evidence and explanations;
- understand the nature and development of scientific knowledge; and
- participate productively in scientific practices and discourse.
  (Duschl, Schweingruber, and Shouse 2007, p. 2)

The following quote from *Ready, Set, Science!* builds on these proficiencies and presents an answer to the question, "Why *practices*?"

> Throughout this book, we talk about "scientific practices" and refer to the kind of teaching that integrates the four strands as "science as practice." Why not use the term "inquiry" instead? Science practice involves doing something and learning something in such a way that the doing and learning cannot really be separated. Thus, "practice" . . . encompasses several of the different dictionary definitions of the term. It refers to doing something repeatedly in order to become proficient (as in practicing the trumpet). It refers to learning something so thoroughly that it becomes second nature (as in practicing thrift). And it refers to using one's knowledge to meet an objective (as in practicing law or practicing teaching). (Michaels, Shouse, and Schweingruber 2008, p. 34)

Scientific inquiry is one form of scientific practice. So, the perspective presented in the *Framework* and *NGSS* is not one of replacing inquiry; rather, it is one of expanding and enriching the teaching and learning of science. Notice the emphasis on teaching strategies aligned with science practices. When students engage in scientific practices, activities become the basis for learning about experiments, data and evidence, social discourse and argumentation, models and tools, and mathematics and for developing the ability to evaluate knowledge claims, conduct empirical investigations, and develop explanations.

QUESTION 8: WHY INCLUDE ENGINEERING?

This question is usually followed with the comment "We already have too much to cover." Like many things, the inclusion of engineering has a history that provides some clarity and justification for my answer. This concern speaks not only to engineering but the rest of the standards as well. Before discussing engineering, I would note that in the final revision of *NGSS*, the team made concerted efforts to maintain the content and guidelines put forth in the *Framework* and reduce the number of performance expectations and associated practices, ideas, and crosscutting concepts.

In the 1960s, technology and engineering were marginalized in the U.S. science curriculum (Rudolph 2002). That said, this era of curriculum reform in the United States did produce one program, *The Man-Made World*, developed by the Engineering Concepts Curriculum Project (ECCP 1971). However, technology was included in other countries (Black and Atkin 1996; Atkin and Black 2003). *Science for All Americans* (Rutherford and Ahlgren 1989) includes chapters on the nature of technology and the "designed world." This reintroduction of technology and engineering was further advanced by these subjects' inclusion in the *Benchmarks for Science Literacy* (AAAS 1993) and the *National Science Education Standards* (NRC 1996). Technology gained further support with the publication of the *Standards for Technological Literacy* (ITEA 2000), *Technically Speaking: Why All Americans Need to Know More About Technology* (Pearson and Young 2002), *Tech Tally: Approaches to Assessing Technological Literacy* (Gamire and Pearson 2006), and *Standards for K–12 Engineering Education?* (NAE 2010).

In the early 21st-century, the acronym *STEM* has emerged as a description of many diverse education initiatives (Bybee 2013). The *T* and *E* in STEM represent *technology* and *engineering.*

As the reader no doubt recognized in Chapter 2, the eight practices of science and engineering overlap in many ways. With the exception of their goals—science identifies questions about the natural world and develops answers in the form of evidence-based explanations, and engineering identifies problems of human needs and aspirations and proposes solutions in the form of new products and processes—science and engineering practices are parallel and complementary in many ways.

There is a need for science teachers and those in teacher education programs to recognize the similarities and differences between science and engineering as disciplines and subsequently the practices that characterize the disciplines.

At the elementary level, there is good news. Many activities that are already in the curriculum are based on engineering problems. Building bridges, dropping eggs, and designing model cars are all examples of engineering in elementary school programs. Unfortunately, these engineering problems and subsequent practices often are referred to erroneously as science. With a clarification of terms and a continuation of the activities, elementary teachers can introduce science and engineering practices and disciplinary core ideas without significant additions to the curriculum. And, as value added, the engineering problems are highly motivating for the students at all grade levels.

At the middle and high school levels, science teachers can begin with the technologies already used—microscopes, telescopes, computers, iPads, and iPhones—as examples of the relationship between science and technology. In addition, there are examples clearly embedded in the practices of science and engineering. Here, I would also add the value of the history of science to show the role of technology and engineering and their contributions to the advancement of scientific knowledge. An excellent contemporary example of the advancement of science due to technology and engineering is the Hubble Space Telescope and its potential successor, the James Webb Space Telescope.

Question 9: What Are the Most Significant Challenges That *NGSS* Present for Science Teachers?

The one word answer: *change*. If I had a second word, it would be *complexity*. National standards by their nature are meant to catalyze change throughout the science education system. One can expect the changes in assessments, curriculum materials, pedagogies, and education technologies to be uneven and inconsistent. One challenge is to continually select the change that best aligns with *NGSS* and benefits student learning. Although it has been mentioned by many, one of the biggest challenges is the shift from science teachers as conveyors of content to facilitators of learning.

The *NGSS* represent a constellation of fundamental changes in the way science has been taught. The *NGSS* require that science teachers understand the vision set forth in *A Framework for K–12 Science Education* (NRC 2012) and have the content knowledge and teaching skills to implement the standards through curriculum and instruction. Ultimately, the potential benefit from the implied *NGSS*-based changes is higher levels of student learning.

While it is the case that classroom practices are the most basic change in the system, science teachers cannot be expected to meet the challenges without the support of colleagues, district administrators, state departments, and national organization. In their reform, it will take a concerted effort at all levels by the science education community.

I introduced complexity as the second challenge. Here, I refer to the requirement to integrate three dimensions in curriculum, instruction, and assessments. Accommodating this challenge requires a rethinking and reforming of the major components of science education.

Question 10: Will Assessments Change?

Yes. This is the simple and straightforward answer. When science teachers ask the question, I often ask for clarification for their reference. Do they mean international assessments such as PISA, national assessments such as NAEP, state assessments, local assessments, or the formative and summative assessments in classrooms? Teachers usually refer to state assessments and the implications they have for accountability. In the future, these will change, but the timing and direction are not clear.

This book concentrates on adapting those assessments teachers use in their classrooms and, in some cases, school districts. Figure 3.4 presents an example prepared by Measured Progress for 5th-grade physical science. Other examples from Measured Progress can be found in Appendixes A–C.

In addition to the Measured Progress unit, you may wish to review other assessments included in Chapters 5–7. The assessments will change. The question I have stressed is "Will curricula and instruction change so they align with the *NGSS* on one side and assessments on the other?"

FIGURE 3.4. AN ASSESSMENT UNIT FOR GRADE 5 PHYSICAL SCIENCE: IS IT A NEW SUBSTANCE?

measured progress™

Alignment

PE	5-PS1-4: Conduct an investigation to determine whether the mixing of two or more substances results in new substances.
DCI	PS1.B: Chemical Reactions: When two or more different substances are mixed, a new substance with different properties may be formed.
SEP	Planning and Carrying Out Investigations: Conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered.
CCC	Cause and Effect: Cause and effect relationships are routinely identified, tested, and used to explain change.
CCSS Connections	W.5.7: Conduct short research projects that use several sources to build knowledge through investigation of different aspects of a topic. W.5.8: Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources.

Figure 3.4 (*continued*)

Is It a New Substance?

Students conduct an investigation to determine if two substances combine to form a new substance. The students are told to mix Substance W with a solution of Substance X dissolved in water. The students need to complete the investigation to gather evidence that supports the claim that a new substance is formed.

Claim: Substance W can combine with Substance X and form a new substance.

Student 1 plans to use a balance to measure the mass of the substances at the beginning and at the end of the investigation.

Student 2 plans to use her sight to observe whether the substances change color in the investigation.

Item 1—MC

Which student's investigation would **most likely** support the claim that a new substance is formed?

- Student 1's, because mass can be more accurately measured than color
- Student 1's, because the mass of a new substance would be equal to that of the previous substance
- Student 2's, because a color change often indicates a new substance
- Student 2's, because color is the most difficult characteristic of a substance to change

KEY: C

Item 2—MC

To compare Student 1's and Student 2's investigations, what variable is **most important** to keep the same during the two investigations?

- the amount of time
- the amount of Substance W
- the equipment used to mix the two substances
- the temperature of the water used to dissolve Substance X

KEY: B

Item 3—CR

Choose one of the students' investigations.

Figure 3.4 (*continued*)

Describe two ways that investigation can be changed to gather more scientific evidence to support the claim. Be sure to explain your reasoning.

SCORING

Full credit
The response describes two ways either investigation can be changed and explains how each method supports the claim.

- perform more trials – this produces repeated data to confirm the results
- vary the amount of Substance W – this helps make sure that a change is not due to uncontrolled variables
- use a zero amount of Substance W (include a negative control) – this helps make sure that Substance X isn't combining with something else
- test another substance that is known to combine with Substance W (include a positive control) – this helps make sure that Substance W can combine as expected (i.e., has not lost reactivity)
- evaluate more characteristics of the substance formed (such as dissolving/not dissolving in water, melting point, etc.) instead of relying on color change or mass change – this supports that a new substance is formed if these identifying properties have changed

Note: Measuring mass can be used as a valid response if the response shows how the mass of Substance W and Substance X change in proportion to the new substance(s). (Only measuring the total mass of the system, as Student 1 did, is not acceptable for credit.)

Partial credit
The response describes one way either investigation can be changed and explains how the method supports the claim, or describes two ways the investigation can be changed but does not include an explanation. Possible responses include any of the changes and/or explanations above.

No credit

- The response may describe changes to the investigation in general, but the response lacks the specifics connected to the formation of new substances.
- Off task or unrelated response.
- Blank/missing response.

CONCLUSION

This chapter provides answers to frequently asked and answered questions. It comes as no surprise that the questions science teachers ask have to do with the changes implied by *NGSS* and the changes required in classroom practices. The ultimate benefit of *NGSS* will be higher levels of student achievement, and facilitating that learning is the classroom science teacher's responsibility. However, teachers cannot be held responsible if they do not have the full support of the science education community.

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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

LS4.A: Evidence of Common Ancestry and Diversity

- 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.

LS4.B: Natural Selection

- 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.

LS4.C: Adaptation

- 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.

LS4.D: Biodiversity and Humans

- 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 crosscutting 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 *A Framework for K-12 Science Education*:

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. ▪ Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena. (1-LS3-1)	**LS3.A: Inheritance of Traits** ▪ 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** ▪ Individuals of the same kind of plant or animal are recognizable as similar but can also vary in many ways. (1-LS3-1)	**Patterns** ▪ Patterns in the natural world can be observed, used to describe phenomena, and used as evidence. (1-LS3-1)

Connections to other DCIs in first grade: N/A

Articulation of DCIs across grade-levels: **3.LS3.A** (1-LS3-1); **3.LS3.B** (1-LS3-1)

Common Core State Standards Connections:

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

AN ENGAGE LESSON → EXPLORATION LESSON(S) → EXPLANATION LESSON(S) → ELABORATION LESSON(S) → EVALUATION LESSON(S)

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

Performance Expectation	Grades K–2	Grades 3–5	Grades 6–8	Grades 9–12
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 *Americas 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

Engage

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.

Exploration

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.

Explanation

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.

Elaboration

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.

Evaluation

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.

USE BACKWARD DESIGN.

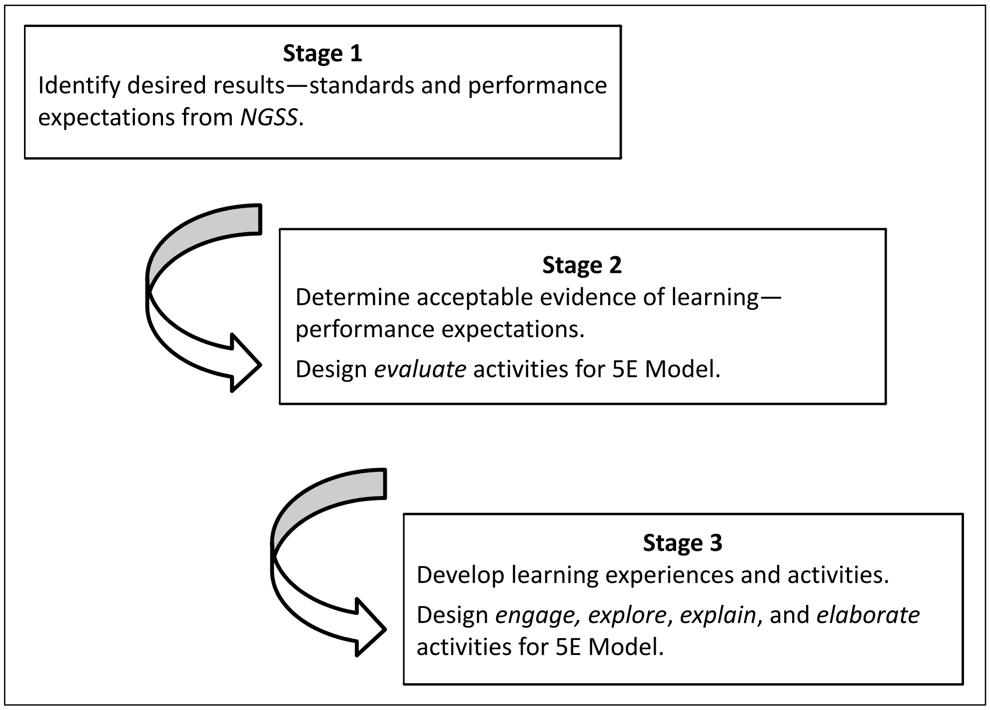
Because performance expectations and foundation boxes in the *NGSS* describe learning outcomes, they are the basis for using backward design for the development or adaptation of curriculum and instruction. Simply stated, the performance expectation can and should be the starting point of backward design.

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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CHAPTER 5

From *NGSS* to Instruction in an Elementary Classroom

The *Next Generation of Science Standards* (*NGSS*) cause elementary school science teachers to ask this question: How will the new standards affect my curriculum and instruction? In this chapter, I use a performance expectation from the life sciences as the basis for a response. My purpose is to provide context and an example of what it means to translate performance expectations into classroom practices. The chapter progresses from a brief review of the performance expectation to an instructional sequence and assessment.

A BASIS FOR INSTRUCTION AND ASSESSMENT

In the *NGSS*, performance expectations are the basis for classroom instruction and assessment. Performance expectations specify a set of learning outcomes. That is, they describe what students should know and be able to do, and they illustrate how students can demonstrate what they have learned. Performance expectations are the criteria for assessments. See Table 5.1 (p. 66) for the performance expectation that serves the basis for classroom instruction and assessments in this chapter.

Performance expectations embody science and engineering practices, disciplinary core ideas, and crosscutting concepts. The three columns beneath the performance expectation are statements from *A Framework for K–12 Science Education* (NRC 2012) and provide detailed content for the three elements in each performance expectation. The reader should note that the performance expectation in Table 5.1 does not include a crosscutting concept. It does include a connection to the nature of scientific knowledge in the foundations box for scientific and engineering practices.

LINKING THE PERFORMANCE EXPECTATION TO AN INTEGRATED INSTRUCTIONAL SEQUENCE

This section uses the BSCS 5E Instructional Model as the basis for a sample instructional sequence based on the performance expectation from the life sciences standard illustrated in Table 5.1. At this point, I will note that the performance expectation in Table 5.1 was the basis for the assessment (i.e., *evaluate* in the 5E model) and developed first. Assessment thus became the basis for the backward design of the instructional sequence.

In Tables 5.2–5.6 (pp. 67–70), I present the phases of the 5E Model in the left column with a general description of each phase. The right column gives a detailed description of more instructional connections among the components of a performance expectation. Finally, discussion below each table is a more detailed description of the classroom instruction for the specific phase of the 5E Model. The performance

TABLE 5.1. PERFORMANCE EXPECTATIONS FOR AN ELEMENTARY SCHOOL INSTRUCTIONAL SEQUENCE

2-LS4 Biological Evolution: Unity and Diversity

2-LS4 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

2-LS4-1. Make observations of plants and animals to compare the diversity of life in different habitats. [Clarification Statement: Emphasis is on the diversity of living things in each of a variety of different habitats.] [Assessment Boundary: Assessment does not include specific animal and plant names in specific habitats.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions. ▪ Make observations (firsthand or from media) to collect data which can be used to make comparisons. (2-LS4-1) -- ***Connections to Nature of Science*** **Scientific Knowledge is Based on Empirical Evidence** ▪ Scientists look for patterns and order when making observations about the world. (2-LS4-1)	**LS4.D: Biodiversity and Humans** ▪ There are many different kinds of living things in any area, and they exist in different places on land and in water. (2-LS4-1)	

Connections to other DCIs in second grade: N/A

Articulation of DCIs across grade-levels: **3.LS4.C** (2-LS4-1); **3.LS4.D** (2-LS4-1); **5.LS2.A** (2-LS4-1)

Common Core State Standards Connections:

ELA/Literacy –

W.2.7 Participate in shared research and writing projects (e.g., read a number of books on a single topic to produce a report; record science observations). (2-LS4-1)

W.2.8 Recall information from experiences or gather information from provided sources to answer a question. (2-LS4-1)

Mathematics –

MP.2 Reason abstractly and quantitatively. *(2-LS4-1)*

MP.4 Model with mathematics. *(2-LS4-1)*

2.MD.D.10 Draw a picture graph and a bar graph (with single-unit scale) to represent a data set with up to four categories. Solve simple put-together, take-apart, and compare problems. *(2-LS4-1)*

The section entitled “Disciplinary Core Ideas” is reproduced verbatim from *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas.* Integrated and reprinted with permission from the National Academy of Sciences.

expectation from the life science standard in Table 5.1 provides the basis for this example. Specifically, elements of the performance expectation are integrated in the instructional sequence.

Some background about earlier grades sets the stage for the discussion. In prior activities, students have several lessons in which they learn that some groups of plants and animals once living on Earth can no longer be found. Dinosaurs are the example that holds the students’ attention. Teachers also point out that some plants and animals were somewhat like those organisms (evidence of common ancestry). In further studies, the children learn the reasons that some plants and animals are extinct—living things can only survive when their needs are met. If the place where organisms live becomes too hot or cold or has too little sunlight, food, or water, then some groups cannot survive (adaptation). In the course of their investigations, the stage is set for children to learn that there are many different kinds of living things and that they exist in very different places (biodiversity).

The next sections discuss a specific teaching sequence based on the BSCS 5E Instructional Model.

Engaging the Learners

TABLE 5.2. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE ENGAGE PHASE

Engage	Description of the *Engage* Phase
Activities capture the students' attention, connect their thinking to the situation, and help them access current knowledge. In this case, what do they know about where different plants and animals live.	This lesson initiates the learning tasks. The activities (1) activate prior knowledge and make connections between past and present learning experiences, and (2) anticipate activities and focus students' thinking on the learning outcomes of the unit. The learners become mentally and physically engaged in the concepts and practices of the curriculum unit.

Ms. Jones began the lesson by asking the children to tell about a plant or animal and explain where the plant or animal lives. The children responded with a variety of common examples: "Whales live in the ocean. "My mother has flowers in her garden." "Some birds live in trees but they fly in the air." "Bugs live in a lot of places."

After the initial responses, Ms. Jones challenged the children to think of plants or animals that lived in weird, unusual, or extreme places. The children became excited as they answered: "I heard that some animals live in the dark, in caves." "The bottom of oceans." "Inside of us." "High on mountains."

At this point in the instructional sequence, Ms. Jones accepted the students' responses. In some cases, she asked for more information and had the students clarify the details of where the organisms lived. She made sure all of the students had an opportunity to give an example.

Exploring the Concepts and Practices

TABLE 5.3. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE EXPLORE PHASE

Exploration	Description of the *Explore* Phase
Students investigate initial ideas and solutions in meaningful contexts. In this case, students are to answer questions about the number and types of plants and animals they observe in different habitats.	This phase provides students with a common base of experiences within which they identify and begin developing concepts, practices, abilities, and skills. Students actively explore the contextual situation through investigations, reading, web searches, and discourse with peers.

Ms. Jones began the class by telling the students that sometimes scientists plan trips to investigate where plants and animals live: "Today you are going to plan an investigation to answer this question: How many different plants and animals can you observe on a trip to our school yard?" She created teams of two students and helped them plan their investigations: "You must organize your observations and keep track of where you look for plants and animals, what you observe, how many different kinds of plants and animals you observe, and the different types of places you find organisms."

Students recorded their observations in a journal. Ms. Jones also told the students they would present their observations to the class.

The students went on their field trip to the school yard.

Explaining the Concepts and Practices

TABLE 5.4. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE EXPLAIN PHASE

Explanation	Description of the *Explain* Phase
Students analyze the exploration. Their understanding is clarified and modified through the introduction of concepts.	This phase focuses on developing an explanation for the situation students have been exploring. They verbalize their conceptual understanding and demonstrate their skills or abilities. Teachers introduce formal labels, definitions, and explanations for concepts, processes, skills, or abilities.

On this day, the students presented their findings. They had prepared charts and formed answers to the questions that guided their field study. Ms. Jones had the students summarize where they went, what plants and animals they observed, how many of each they observed, and the type of place they observed. Ms. Jones also asked them how their investigation was similar to what scientists do.

After the presentations, Ms. Jones provided a clear summary for the students: "Like scientists, you were making observations to learn about the types of plants and animals that live in different places." "The different places where organisms live are called their habitat." "Also, scientists make observations and look for patterns when they are trying to answer questions about the world."

Elaborating on the Concepts and Practices

TABLE 5.5. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE ELABORATE PHASE

Elaboration	Description of the *Elaborate* Phase
Students have opportunities to expand and apply their understanding of the concepts within new contexts and situations. Here, they apply their understanding of diversity by organizing pictures of plants and animals in very different habitats—land and water.	These lessons extend students' conceptual understanding through opportunities for students to apply knowledge, skills, and abilities. Through new experiences, the learners transfer what they have learned and develop broader and deeper understanding of the concepts and skills they learned in prior lessons.

In this lesson, Ms. Jones had students collect pictures of three different organisms that live on land and three that live in water. She gave the students a special challenge: "See which team can identify the most diverse groups of organisms that live in different habitats on land and in water."

Students first tried to identify diverse examples, then searched magazines and the internet for pictures. When they presented their results to the class, it was clear that there are many different kinds of living things and that they exist in different places on land and in water, as Ms. Jones summarized.

Evaluating the Concepts and Practices

TABLE 5.6. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE EVALUATE PHASE

Evaluation	Description of the *Evaluate* Phase
Students assess their understanding of the concepts, and teachers have the opportunity to assess student learning.	This phase emphasizes students assessing their understanding and abilities and provides opportunities for teachers to evaluate students' understanding of concepts and development of practices identified in performance expectations.

Overview
Students observe pictures of organisms in different habitats to demonstrate their understanding of the diversity of plants and animals. The pictures or line drawings show two distinctly different habitats. The differences between the plants and animals in the different habitats should be obvious.

QUESTION 1

The pictures below show plants and animals and where they live. Include examples of multiple individuals of the same species to determine if students are comparing the total number of organisms or the number of different kinds of organisms. Describe the different types of plants and animals in these two habitats.

SCORING/Question 1

Full credit
The response describes how the plants and animals are different in the respective habitats.

Partial credit
Students identify which habitat has more (or fewer) kinds of organisms but does not provide specific observations (e.g., quantities) to support their conclusion.

QUESTION 2

Based on the pictures, which of the following best describes what you did that is like what scientists do with plants and animals?

- I observed where plants and animals live. YES or NO
- I noticed the difference between plants that live in different places. YES or NO
- I looked for patterns and made observations about the world. YES or NO

SCORING/Question 2

Full credit
YES, YES, YES

Partial credit
One or two YES and one NO

No credit
All NO

TABLE 5.7. SUMMARY OF TEACHING AND ASSESSMENT THAT SUPPORT THE *NEXT GENERATION SCIENCE STANDARDS* (*NGSS*) (ELEMENTARY SCHOOL)

NGSS-Based Performance Expectation	Teaching Strategies	Assessment Strategies
Make observations of plants and animals to compare the diversity of life in different habitats.	**Engage** Students are asked to give an example of a plant or animal and tell where (in what habitat) that animal lives. **Explore** The teacher has students plan a trip to answer the question, "How many different plants and animals can you observe on a trip to the (school yard, park, or vacant lot)?" Teams of two students go into the school yard or community and identify a habitat (e.g., grass, vacant lot) and identify as many different types of plants and animals as possible. **Explain** Students present their findings from the field trip and the teacher introduces the disciplinary core idea that "there are many different kinds of living things in any area, and they exist on land and in water." **Elaborate** Students are given a task to collect pictures of three different organisms (plants or animals) that live in water and on land. Students display their pictures and describe the differences in the organisms and their different habitats.	**Evaluate** Students are given pictures of plants and animals that live in different habitats. Students are asked to describe the different types of plants and animals that live in the habitats in the pictures and identify what they did that is like what scientists do.

TABLE 5.8. SUMMARY OF THE INTEGRATION OF PRACTICES, DISCIPLINARY CORE IDEAS, AND CROSSCUTTING CONCEPTS

5E Model Phase	Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engage		Biodiversity and Humans (Background)	
Explore	Planning and Carry Out Investigations (Foreground)	Biodiversity and Humans (Background)	
Explain	Planning and Carrying Out Investigations (Background)	Biodiversity and Humans (Foreground)	
Elaborate	Planning and Carrying Out Investigations (Background)	Biodiversity and Humans (Foreground)	
Evaluate	Planning and Carrying Out Investigations (Foreground)	Biodiversity and Humans (Foreground)	

CONCLUSION

Implementing the standards does present significant challenges. There is the obvious and immediate challenge of classroom instruction. There also is the second long-term challenge of contributing to students' progressive understanding across the K–12 curriculum. This chapter presented one teacher's response to the challenge of translating standards to classroom practices.

REFERENCE

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CHAPTER 6

From *NGSS* to Instruction in a Middle School Classroom

The *Next Generation Science Standards* (*NGSS*) have initiated changes in several important components of science education. For middle school science teachers, one of the most fundamental changes involves curriculum, instruction, and assessments. This chapter uses performance expectations from the life sciences—in particular, Biological Evolution: Unity and Diversity—as the basis for a description of how *NGSS* might be translated to a middle school classroom.

This chapter first introduces two performance expectations that describe competencies or learning outcomes for middle school life sciences. I then describe an instructional sequence, including an assessment.

I developed this instructional sequence using backward design. That is, I worked on the assessment (i.e., the *evaluate* in the BSCS 5E Instructional Model) and then developed the other phases of the instructional sequence. This process was iterative as I went back and forth between the instructional lessons and the assessment, with subsequent modifications to both.

THE BASIS FOR INSTRUCTION AND ASSESSMENT

The *NGSS* performance expectations serve as the basis for classroom instruction and assessments. They specify a set of learning outcomes. That is, the performance expectations describe the competencies students should develop and illustrate how students can demonstrate what they have learned. Performance expectations for the examples in this chapter are illustrated in Table 6.1 (p. 74).

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

LINKING PERFORMANCE EXPECTATIONS TO AN INTEGRATED INSTRUCTIONAL SEQUENCE

This section uses the BSCS 5E Instructional Model as the basis for an example of an instructional sequence based on a cluster of performance expectations from the life sciences standard.

In Tables 6.2–6.6 (pp. 76–80), the phases of the 5E Instructional Model are in the left column with a general description of each phase. The right column gives a detailed description of more instructional connections among the three components

TABLE 6.1. PERFORMANCE EXPECTATIONS FOR A MIDDLE SCHOOL INSTRUCTIONAL SEQUENCE

MS-LS4-4 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. [Clarification Statement: Emphasis is on using simple probability statements and proportional reasoning to construct explanations.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. ▪ Apply scientific ideas to construct an explanation for real-world phenomena, examples, or events. (MS-LS4-2) ▪ Construct an explanation that includes qualitative or quantitative relationships between variables that describe phenomena.	**LS4.B: Natural Selection** ▪ Natural selection leads to the predominance of certain traits in a population, and the suppression of others.	**Cause and Effect** ▪ Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability. (MS-LS4-4),(MS-LS4-5),(MS-LS4-6)

Connections to other DCIs in this grade-band:
MS.LS2.A ; **MS.LS3.A** ; **MS.LS3.B**

Articulation of DCIs across grade-bands:
3.LS3.B ; **3.LS4.B** ; **HS.LS2.A** ; **HS.LS3.B** ; **HS.LS4.B** ; **HS.LS4.C**

Common Core State Standards Connections:

ELA/Literacy –	
RST.6-8.1	Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions *(MS-LS4-4)*
RST.6-8.9	Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. *(MS-LS4-4)*
WHST.6-8.2	Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS4-4)
WHST.6-8.9	Draw evidence from informational texts to support analysis, reflection, and research. (MS-LS4-4)
SL.8.1	Engage effectively in a range of collaborative discussions (one-on-one, in groups, teacher-led) with diverse partners on grade 6 topics, texts, and issues, building on others' ideas and expressing their own clearly. *(MS-LS4-4)*
SL.8.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. *(MS-LS4-4)*
Mathematics –	
6.RP.A.1	Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. *(MS-LS4-4)*
6.SP.B.5	Summarize numerical data sets in relation to their context. *(MS-LS4-4)*
7.RP.A.2	Recognize and represent proportional relationships between quantities. *(MS-LS4-4)*

MS-LS4-6 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

MS-LS4-6. Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time. [Clarification Statement: Emphasis is on using mathematical models, probability statements, and proportional reasoning to support explanations of trends in changes to populations over time.] [Assessment Boundary: Assessment does not include Hardy Weinberg calculations.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking Mathematical and computational thinking in 6–8 builds on K–5 experiences and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. ▪ Use mathematical representations to support scientific conclusions and design solutions.	▪ Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes.	**Cause and Effect** ▪ Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.

Connections to other DCIs in this grade-band:
MS.LS2.A ; **MS.LS2.C** ; **MS.LS3.B** ; **MS.ESS1.C**

Articulation of DCIs across grade-bands:
3.LS4.C ; **HS.LS2.A** ; **HS.LS2.C** ; **HS.LS3.B** ; **HS.LS4.B** ; **HS.LS4.C**

Common Core State Standards Connections:

Mathematics –	
6.RP.A.1	Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. *(MS-LS4-6)*
6.SP.B.5	Summarize numerical data sets in relation to their context. *(MS-LS4-6)*
7.RP.A.2	Recognize and represent proportional relationships between quantities. *(MS-LS4-6)*

of a performance expectation. Finally, below each table, I provide a description of the instructional phase. Two performance expectations from the life science standard provide the basis for this example. The performance expectations are integrated in the instructional sequence. Following the figures is a narrative describing classroom instruction for each phase.

Background about earlier grades and what students should have learned by grade 5 sets the stage for this discussion of an integrated instructional sequence.

In grades K–5, students learned that fossils provide evidence about the types of organisms 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.

Relative to the development of their understanding of natural selection, students should understand that sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates, and reproducing.

For adaptation, students had opportunities to learn that changes in an organism's habitat are sometimes beneficial and sometimes harmful. For any particular environment, some kinds of organisms survive and reproduce, and others will not. Over time, the characteristics of organisms that survive and reproduce will increase in the population.

By grade 5, students should be able to apply their initial knowledge of natural selection and adaptation to understand that changes in habitats affect the populations of organisms living there. Human beings, like all other organisms, obtain living and nonliving resources from their environments and may be affected by changes to those habitats.

The instructional sequence uses fossils to develop concepts about evidence supporting common ancestry and diversity, natural selection, and subsequent adaptation. The practices of analyzing and interpreting data and constructing explanations are included as learning outcomes. The crosscutting concepts of cause and effect also are integrated. The next section discusses a teaching sequence based on the 5E Instructional Model and the life science performance expectations.

Engaging the Learners

TABLE 6.2. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE ENGAGE PHASE

Engage	Description of the *Engage* Phase
Activities capture the students' attention, connect their thinking to the situation, and help them access current knowledge. Here, the fossils engage the students' interest.	This sequence of lessons initiates the learning tasks. The activities should (1) activate prior knowledge and make connections between past and present learning experiences, and (2) anticipate activities and focus students' thinking on the learning outcomes of current activities. The learner should become mentally engaged in the concepts, practices, abilities, and skills of the curriculum unit.

Ms. Evans began the teaching sequence with a task students originally perceived as easy—describing the characteristics of two brachiopods to see if change has occurred. Ms. Evans gave each student two similar but slightly different fossils and asked the students, "Can any changes or trends of change be identified between the two fossils?" The openness and ambiguity of the questions resulted in mixed responses: "Yes, I can see a difference." "How do you expect me to see a change?"

Ms. Evans asked for a justification of each answer and gently challenged the students' responses by posing other questions, such as, "How do you know? How could you support your answer? What evidence would you need? What if these fossils were from the same rock formation? How do you know that the differences are not normal variations in this species? What if the two fossils were from rock formations deposited 10 million years apart? Can you tell whether or not changes in organisms have occurred by examining only two samples?"

Exploring the Concepts and Practices

TABLE 6.3. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE EXPLORE PHASE

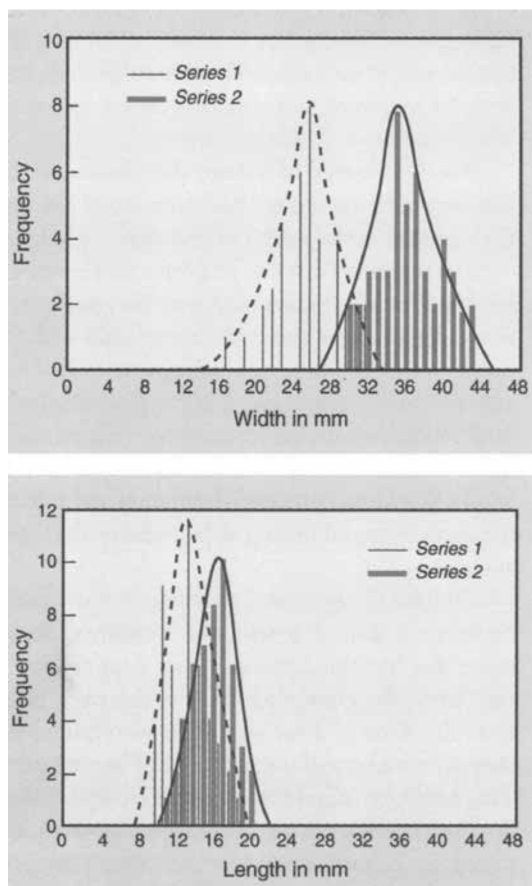
Exploration	Description of the *Explore* Phase
Students investigate initial ideas and solutions in contexts that hold their attention and have personal meaning—in this case, the physical examination of fossils.	This phase provides students with a common base of experiences within which they identify and begin developing concepts, practices, abilities, and skills. Students actively explore the contextual situation through investigations, reading, web searches, and discourse with peers.

Ms. Evans distributed two trays, each with about 100 carefully selected fossil brachiopods. She asked the students to describe the fossils. After they had time to examine the fossils, she heard descriptions such as "They look like butterflies" and "They are kind of triangular with a big middle section and ribs." Ms. Evans then asked if there were any differences between the fossils in the two trays. The students quickly concluded that they could not really tell any differences based on the general description, so Ms. Evans asked how they could tell if the fossil populations were different. From the ensuing discussion, students determined that quantitative descriptions of specific characteristics—such as length, width, or number of ribs—could be used.

Ms. Evans placed the students in groups of four and told them to measure, record, and graph some characteristics of the brachiopod populations. The students decided what they wanted to measure and how to do it. They worked for two periods measuring and entering their data on length or width of the brachiopods in a database. When all data were entered, summarized, and graphed, the class results resembled those displayed in Figure 6.1.

The students began examining the graphs showing frequency distribution of the length or width of fossils. As the figures indicate, the results for

FIGURE 6.1. GRAPH SHOWING CHARACTERISTICS OF BRACHIOPOD POPULATIONS



either dimension showed a continuous variation for the two populations. Students observed that regardless of the dimension measured, the mean for the two populations differs.

Ms. Evans then asked the groups to engage in a discussion based on their analysis of the data represented in the graphs. What might cause the differences in the graphs? What explains the similarity in the graph? The student groups were encouraged to formulate explanations for the changes based on the evidence they had.

Explaining the Concepts and Practices

TABLE 6.4. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE EXPLAIN PHASE

Explanation	Description of the *Explain* Phase
Students analyze the exploration. Their understanding is clarified and modified through the introduction of concepts.	This phase focuses on developing an explanation for the situation students have been exploring. They verbalize their conceptual understanding and demonstrate their skills or abilities. Teachers introduce formal labels, definitions, and explanations for concepts, processes, skills, or abilities.

In the next class, after the graphs were drawn, Ms. Evans asked the students to explain the differences in the populations. The students suggested several general explanations: These are simply different kinds of brachiopods; the differences in the means for length and width demonstrate adaptions in the populations; the differences are a result of normal variations in the populations.

Ms. Evans took time to provide background information that the students should consider. Ms. Evans explained how some organisms are fossilized and others are not, and how the fossil record provides evidence for the history of life on Earth. She noted that adaptation occurs in populations, and changes in a population's environment result in selection for those organisms best fit for the new environment. She continued with a few questions that again challenged the students' thinking: "Did the geological evidence indicate the environment changes? How can you be sure that the fossils were not from different environments and deposited within a scale of time that would not explain the degree of evolutionary change? Why would natural selection for differences in length or width of brachiopods occur? What differences in structure and function are represented in the length or width of brachiopods?"

In the course of the discussion, Ms. Evans also explained that multiple lines of evidence strengthen support for proposed scientific explanations. The students needed to use the evidence from their investigations and other reviews of scientific literature to develop scientific explanations for the aforementioned general explanations. They took the next class period to complete an assignment that had them construct an evidence-based explanation of how natural selection may lead to increases or decreases of specific traits in a population.

Elaborating on the Concepts and Practices

TABLE 6.5. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE ELABORATE PHASE

Elaboration	Description of the *Elaborate* Phase
Students have opportunities to expand and apply their understanding of the concepts within new contexts and situations.	These 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.

At the beginning of the period, Ms. Evans presented pictures of several different organisms. She asked, "Can you identify any similarities and differences in the organisms?" The students struggled to identify similarities, but they could identify differences. The students next observed pictures showing the embryological development of several species. The students immediately recognized the similarities in the embryological development across different species. Ms. Evans pointed out that such observations are used to identify relationships not evident in the fully formed anatomy of the respective organisms.

Student groups used the observations from prior lessons to begin constructing explanations about the similarities and differences of life on Earth.

After initial discussions, Ms. Evans indicated that the students would prepare reports of similarities and differences of organisms and how they may have evolved.

After work by the students on background research and preparation, Ms. Evans organized a small conference at which the students' papers were presented and discussed. Students' presentations focused on their ability to ask skeptical questions, evaluate the use of evidence, assess the understanding of biological concepts, and review aspects of scientific practices. During the discussions, students were directed to address the following questions: What evidence would you look for that might indicate organisms had common ancestors? What constitutes the same or different species?

Ms. Evans assessed how well students prepared and presented their reports. The specific evaluations included analyzing patterns of data; constructing explanations; analyzing graphs; and explaining fossil records for evidence of the history of life on Earth and the crosscutting concepts, stability and change, and cause and effect.

Evaluating the Concepts and Practices

TABLE 6.6. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE EVALUATE PHASE

Evaluation	Description of the *Evaluate* Phase
Students assess their understanding of the concepts, and teachers have the opportunity to assess student learning.	This phase emphasizes students' assessing their understanding and abilities and provides opportunities for teachers to evaluate students' understanding of concepts and practices identified in performance expectations.

Overview

Students construct an explanation based on evidence (qualitative or quantitative) that describes how genetic variations (based on natural selection) of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. The assessment also evaluates how students use mathematical representations (a model) to support explanations of how natural selection (over generations) may lead to increases and decreases of specific traits (trends in changes) in populations over time. The traits that are successful become more common. The cause-and-effect relationships are described using probability.

QUESTION 1

THE CHEETAH

There are many different species of plants and animals. Within any one species, there is variation among individuals. Many different plants and animals live on the grasslands in Africa, and among these is the cheetah. Cheetahs are the fastest and among the most agile land animals. In short bursts when chasing prey, they reach speeds of 70–75 miles per hour (112–120 kilometers per hour) and are able to slow down and turn quickly.

Differences in the traits of the cheetahs may be affected by environmental and genetic factors.

1. Describe a trait that might vary among individual cheetahs due to genetic factors, and explain how genetic factors might have caused the differences.
2. Describe a trait that might vary among individual cheetahs due to environmental factors, and explain how environmental factors might have caused the differences.

SCORING/Question 1

Full credit
Part 1: Response describes a variation in a specific trait of cheetahs likely to be affected by genetic factors AND provides a reasonable explanation of how the differences might be affected by genetic factors. (*Note:* Response does *not* need to explain specific mechanisms of genetic inheritance or genetic expression.)

Sample response: Cheetahs might have different patterns of spots on their fur. The pattern on a cheetah's fur might be affected by the genes it inherits from it parents.

Part 2: Response describes a variation in a different specific trait of cheetahs likely to be affected by environmental factors AND provides a reasonable explanation how the differences might be affected by environment factors.

Example response: Cheetahs might have different body masses. The differences in body mass might be affected by the availability of food (prey) in the area where the cheetah lives.

Partial credit
Student has either part 1 or part 2 correct but does not respond correctly to the other part.

No credit
Other responses or no answers.

QUESTION 2

Over time, species of plants on African grasslands have adapted to different environments. Provide a brief scientific explanation for how environmental and genetic factors may have influenced the growth of plants.

SCORING/Question 2

Full credit
Explanation includes indication that environmental conditions (such as food, light, space, or water) and genetic factors may have positive or negative effects on growth. Plants that have genetic traits best suited for changes in the environment are most likely to survive and pass traits on to subsequent generations.

No credit
Other responses, or no answer.

QUESTION 3

The cheetah can run faster than 70 mph. However, previous generations of cheetahs did not run this fast. Which one of the following BEST explains how the ability to run fast developed within the species?

A Cheetahs practiced running for generation after generation.

B. Cheetahs learned to run fast in order to catch enough prey to survive.

C. Cheetahs that are faster and more agile catch more prey and are more likely to survive and have more cubs.

D. Cheetahs that developed stronger muscles passed on this trait.

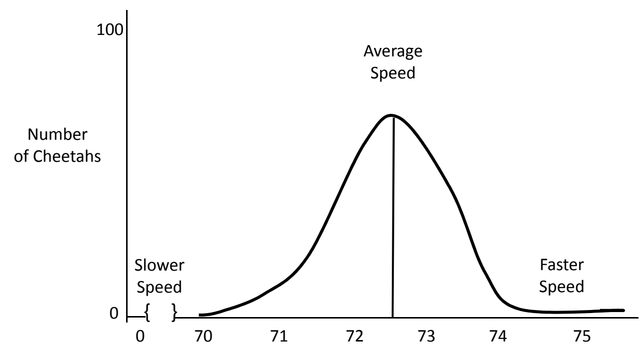
SCORING/Question 3

Full credit
C

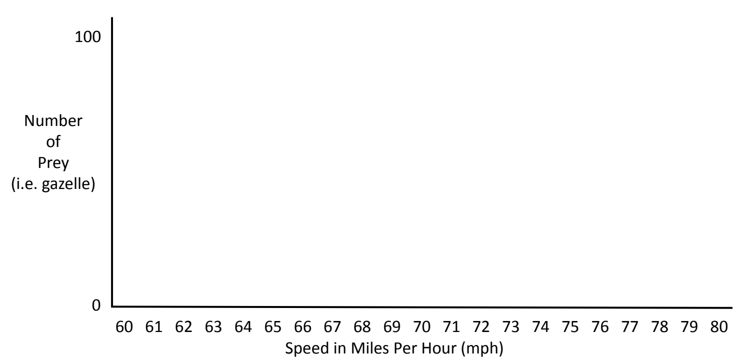
Partial credit
Other responses, or no answer.

QUESTION 4

The curve below shows the average and range of speeds of cheetahs.



Draw a curve representing the average speed and range of speeds that you would predict for cheetah's prey, such as a gazelle.



Provide a brief explanation of your answer.

SCORING/Question 4

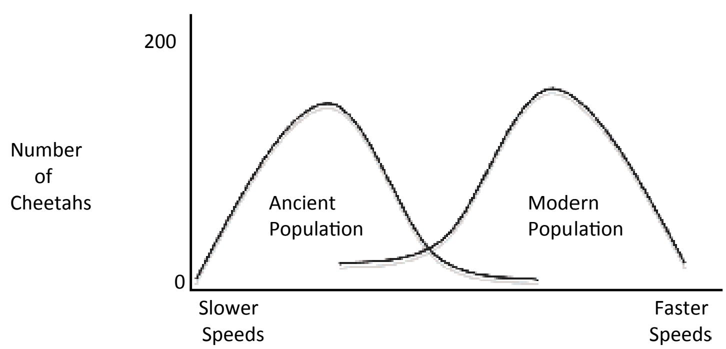
Full credit
The curve should indicate a speed slightly slower than the average speed of the cheetah. For example, the range of speed of prey might be between 65 and 70 mph.

The explanation may include different speeds for different prey and variations in prey such as younger or older, sick, injured, and so on. But on average, the prey should have a range of speeds with an average lower than the cheetah.

Partial credit
The explanation of slower average speed of prey is correct, but the student does not represent the range of speeds using the graph.

QUESTION 5

Scientists use mathematical representations to support their explanations. The graph below shows changes in the average speed of cheetahs over many generations.



Use the information in this graph to provide evidence supporting an explanation of how natural selection could have caused the change in the average speed of cheetahs over many generations.

SCORING/Question 5

Full or partial credit
Following are criteria for a fully correct response (anything in parentheses is optional). The first three criteria are essential for full credit (i.e., variation in traits, some variations have advantages, traits are inheritable). The fourth bullet is a synthesis of the first three to explain the shift in distribution of traits in the population over time.

- There is variation in speed within the cheetah population for any given generation. (*Optional:* Most of the cheetahs have a speed close to the average. There are a small number of cheetahs that are much slower than the average speed and a small number of cheetahs that are much faster than the average speed.)

- Individual cheetahs within the population that are faster (than the average speed) are more likely to survive (by catching more prey) and reproduce (successfully raise more cubs). (*Optional:* Not all cheetahs will survive or reproduce successfully due to limiting factors such as amount of prey, availability of mates, availability of territory, and so on. More cheetahs cubs are born than can ultimately survive and be supported.)
- The speed of an individual cheetah is affected by genetic factors passed on from parent to offspring. With each new generation, the cheetahs that were faster contributed more offspring and genes to the new population, which causes the average speed of the population to be higher (compared to the previous generation).
- Other environmental factors (such as increase in the average speed of prey populations, reduction in prey population size, etc.) can continue (reinforce) the selection pressure over time.

TABLE 6.7. SUMMARY OF THE THREE DIMENSIONS AND AN INTEGRATED INSTRUCTIONAL SEQUENCE

5E Model Phase	Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engage	Analyzing and Interpreting Data (Background)	Evidence of Common Ancestry and Natural Selection (Background)	Cause and Effect (Background)
Explore	Using Mathematics Analyzing and Interpreting Data (Foreground)	Evidence of Common Ancestry and Natural Selection Adaptation (Background)	Cause and Effect (Background)
Explain	Constructing Explanations Nature of Science (Foreground)	Adaptation: Natural Selection (Foreground)	Cause and Effect (Foreground)
Elaborate	Constructing Explanations Using Mathematical Representations (Foreground)	Adaptation: Natural Selection (Foreground)	Cause and Effect (Background)
Evaluate	Performance Expectations (All of above)	Performance Expectations (All of above)	Performance Expectations (All of above)

TABLE 6.8. SUMMARY OF TEACHING AND ASSESSMENT THAT SUPPORT THE *NGSS* (MIDDLE SCHOOL)

NGSS-Based Performance Expectation	Teaching Strategies	Assessment Strategies
Construct an explanation based on evidence that describes how genetic variation of traits in a population increases some individuals' probability of surviving and reproducing in a specific environment. Use mathematical representation to support explanations of how natural selection may lead to increases or decreases of specific traits in populations over time.	**Engage** Students describe the characteristics of two fossil brachiopods to see if changes have occurred. As students provide answers, they are asked, "How can you support your answer? What is the evidence? How could you get evidence to support your explanation? What if the fossils came from rock formations deposited 10 million years apart?" **Explore** Students first describe the measurement record and graph some characteristics (e.g., length or width) of brachiopod populations. The graphs (i.e., frequency distributions) show a continuous variation between the two populations. Students propose answers to explain the similarities and differences in the graphs. They propose explanations based on the evidence. **Explain** The students present their explanations for the differences in populations. The teacher provides scientific explanations on fossilization, the fossil record, adaptation, and natural selection. The explanation also includes the role of evidence, a connection to the graphs, and the importance of multiple lines of evidence in a scientific explanation. **Elaborate** Students examine pictures of several organisms to identify similarities and differences. Students review pictures of embryological development and recognize similarities. Students prepare reports on the similarities and differences of organisms and how they evolved.	**Evaluate** Using the cheetah as an example, students answer questions and construct an explanation of how genetic variation and selection may result in some individuals surviving and reproducing. The assessment has students using mathematical representation to support explanations of changes in the distribution of traits in a population over time.

CONCLUSION

Implementing the standards does present significant challenges. There is the obvious and immediate challenge of classroom instruction. There also is the second long-term challenge of contributing to students' progressive understanding across the K–12 curriculum.

REFERENCES

Bybee, R., J. Taylor, A. Gardner, P. Van Scotter, J. Carlson, A. Westbrook, and N. Landes. 2006. *The BSCS 5E instructional model: Origins, effectiveness, and applications.* Colorado Springs, CO: BSCS.

National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.

CHAPTER 7

From *NGSS* to Instruction in a High School Classroom

This chapter first presents performance expectations that describe the competencies and content for instruction and assessment in a high school biology class. This is followed by a description of a teaching sequence that integrates the practices, core ideas, and crosscutting concepts through a series of investigations, activities, explanations, and presentations. The instructional sequence is based on the BSCS 5E Instructional Model described in Chapter 4 and briefly summarized in this chapter.

The final phase of the 5E model, *evaluate*, is the assessment described at the conclusion of the instructional sequence. Although the assessment is the concluding phase, it was developed first and then used as the basis for an iterative process of proposing the various phases of instruction and revising the assessments.

THE BASIS FOR INSTRUCTION AND ASSESSMENT

In the *Next Generation Science Standards* (*NGSS*), performance expectations are the foundation for classroom instruction and assessment. Performance expectations specify a set of learning outcomes or competencies. That is, they describe what students should know and be able to do and illustrate how students can demonstrate what they have learned. See Table 7.1 (pp. 88–89) for the performance expectations that are the basis for classroom instruction and assessments in this chapter.

LINKING PERFORMANCE EXPECTATIONS TO AN INTEGRATED INSTRUCTIONAL SEQUENCE

This section uses the BSCS 5E Instructional Model (Bybee et al. 2006) as the organizer for an example that links performance expectations to classroom instruction. First, I provide a brief summary about earlier grades and what students should have learned through grade 8 sets the stage for discussion of the integrated instructional sequence.

By eighth grade, students should have learned that fossils are mineral replacements, preserved remains, or traces of organisms that lived in the past. Different layers of sedimentary rock provide evidence of Earth's history and changes in organisms whose fossil remains have been found in those rock formations. The fossil record documents the existence, diversity, extinction, and change over time of many life forms. Anatomical similarities and differences among various organisms living today and the fossil record enable scientists to reconstruct evolutionary history and infer lines of evolutionary descent with modifications. Scientists also compare the

TABLE 7.1. PERFORMANCE EXPECTATIONS FOR A HIGH SCHOOL INSTRUCTIONAL SEQUENCE

HS-LS4 Biological Evolution: Unity and Diversity

HS-LS4 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.]

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.]

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.* [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. (HS-LS4-3)

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create or revise a simulation of a phenomenon, designed device, process, or system. (HS-LS4-6)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS4-2),(HS-LS4-4)

Disciplinary Core Ideas

LS4.A: Evidence of Common Ancestry and Diversity

- Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence. (HS-LS4-1)

LS4.B: Natural Selection

- Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. (HS-LS4-2),(HS-LS4-3)
- The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. (HS-LS4-3)

LS4.C: Adaptation

- Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. (HS-LS4-2)
- Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. (HS-LS4-3),(HS-LS4-4)

Crosscutting Concepts

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-LS4-1),(HS-LS4-3)

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS4-2),(HS-LS4-4),(HS-LS4-5),(HS-LS4-6)

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. (HS-LS4-1),(HS-LS4-4)

Table 7.1 (*continued*)

Connections to other DCIs in this grade-band: **HS.LS2.A** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4),(HS-LS4-5); **HS.LS2.D** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4),(HS-LS4-5); **HS.LS3.A** (HS-LS4-1); **HS.LS3.B** (HS-LS4-1),(HS-LS4-2) (HS-LS4-3),(HS-LS4-5); **HS.ESS1.C** (HS-LS4-1); **HS.ESS2.D** (HS-LS4-6); **HS.ESS2.E** (HS-LS4-2),(HS-LS4-5),(HS-LS4-6); **HS.ESS3.A** (HS-LS4-2),(HS-LS4-5),(HS-LS4-6); **HS.ESS3.C** (HS-LS4-6); **HS.ESS3.D** (HS-LS4-6)	
Articulation across grade-bands: **MS.LS2.A** (HS-LS4-2),(HS-LS4-3),(HS-LS4-5); **MS.LS2.C** (HS-LS4-5),(HS-LS4-6); **MS.LS3.A** (HS-LS4-1); **MS.LS3.B** (HS-LS4-1),(HS-LS4-2),(HS-LS4-3); **MS.LS4.A** (HS-LS4-1); **MS.LS4.B** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4); **MS.LS4.C** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4),(HS-LS4-5); **MS.ESS1.C** (HS-LS4-1); **MS.ESS3.C** (HS-LS4-5),(HS-LS4-6)	
Common Core State Standards Connections:	
ELA/Literacy –	
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-LS4-1)*,(HS-LS4-2),*(HS-LS4-3)*,(HS-LS4-4)
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS4-5)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-LS4-1)*,(HS-LS4-2),*(HS-LS4-3)*,(HS-LS4-4)
WHST.9-12.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. *(HS-LS4-6)*
WHST.9-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-LS4-6)
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *(HS-LS4-1)*,(HS-LS4-2),*(HS-LS4-3)*,(HS-LS4-4),(HS-LS4-5)
SL.11-12.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. *(HS-LS4-1)*,*(HS-LS4-2)*
Mathematics –	
MP.2	Reason abstractly and quantitatively. *(HS-LS4-1)*,(HS-LS4-2),(HS-LS4-3),*(HS-LS4-4)*,*(HS-LS4-5)*
MP.4	Model with mathematics. *(HS-LS4-2)*

The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

The section entitled "Disciplinary Core Ideas" is reproduced verbatim from *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas.* Integrated and reprinted with permission from the National Academy of Sciences.

embryological development of different species looking for similarities that show relationships not evident in the anatomy of mature organisms.

Relative to natural selection, by eighth grade, students should know that genetic variations among individuals in a population give some individuals an advantage in surviving and reproducing in their environment. Natural selection leads to the predominance of certain traits in a population and the suppression of others. They should be familiar with the concept of adaptation as an important process by which the distribution of traits in a population changes over time.

Finally, students come to high school knowing that biodiversity describes the many extant life forms that have adapted to the variety of conditions on Earth. Biodiversity includes genetic variation within a species, in addition to species variation in different habitats and ecosystems. Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services such as water purification and recycling. Humans rely on ecosystem services.

The next section discusses a specific teaching sequence based on the 5E Instructional Model and the life science standard Biological Evolution: Unity and Diversity.

Engaging the Learners

TABLE 7.2. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE ENGAGE PHASE

Engage	Description of the *Engage* Phase
Activities capture the students' attention, connect their thinking to the situation, and help them access their current knowledge. In this case, what they currently understand about biological evolution.	This sequence of lessons initiates the learning tasks. The activities (1) activate prior knowledge and make connections between past and present learning experiences, and (2) anticipate activities and focus students' thinking on the learning outcomes of current activities. The learner should become mentally engaged in the concepts, practices, abilities, and skills of the curriculum unit.

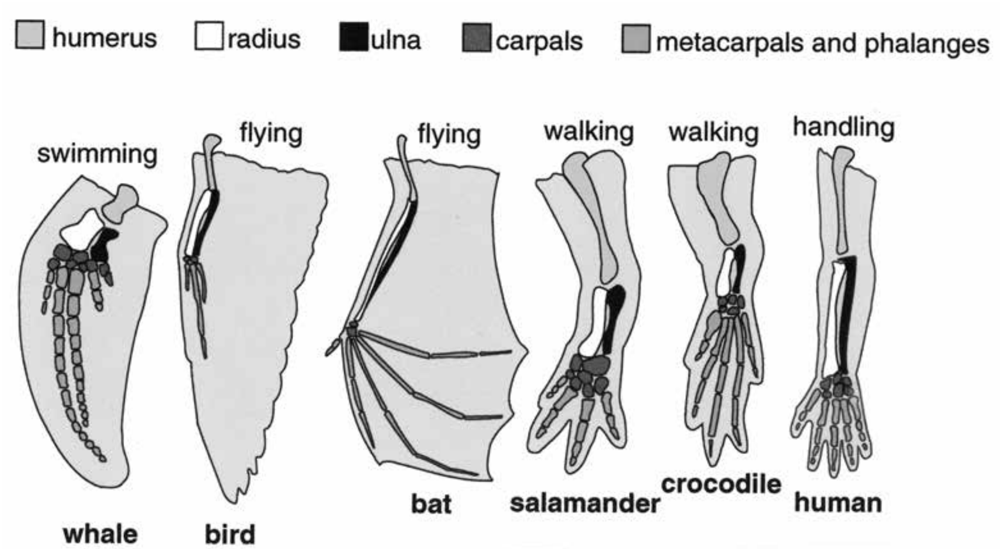
As students entered the room, they saw pictures of many different organisms displayed around the room. Ms. Lopez directed the class to study the pictures, which represented diverse types of organisms, including several extinct species. She asked the students how they would group the different organisms. The groupings students identified included plants and animals, vertebrates and invertebrates, and living and extinct organisms. Ms. Lopez asked, "How are some of the organisms similar? What are some characteristics that plants share? That animals share? How do some similar organisms also display differences?" This first activity concluded with a discussion of why there are different organisms and how organisms may have changed.

The initial activity was an opportunity for students to present what they know about the similarities and differences among organisms—the major themes of unity and diversity. The engaging instruction continued with a second activity.

In a second activity, Ms. Lopez engaged students with a handout displaying the "arms" of six different organisms (see Figure 7.1). Individually, students examined the diagrams displaying the arms of diverse organisms. She asked students to first discuss the different organisms. She offered questions: "What is their habitat? How does the arm structure function in a way that helps the organisms survive? Can they explain how the arms demonstrate the unity and diversity of organisms?"

These activities began building an understanding of evidence for evolution and students' current understanding of biological evolution. Ms. Lopez directly introduced other concepts of evolution during this lesson.

FIGURE 7.1. VARIATIONS IN THE APPENDAGES OF ORGANISMS



Source: BSCS 2008. Level 2. Adapted with permission.

Exploring the Concepts and Practices

TABLE 7.3. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE EXPLORE PHASE

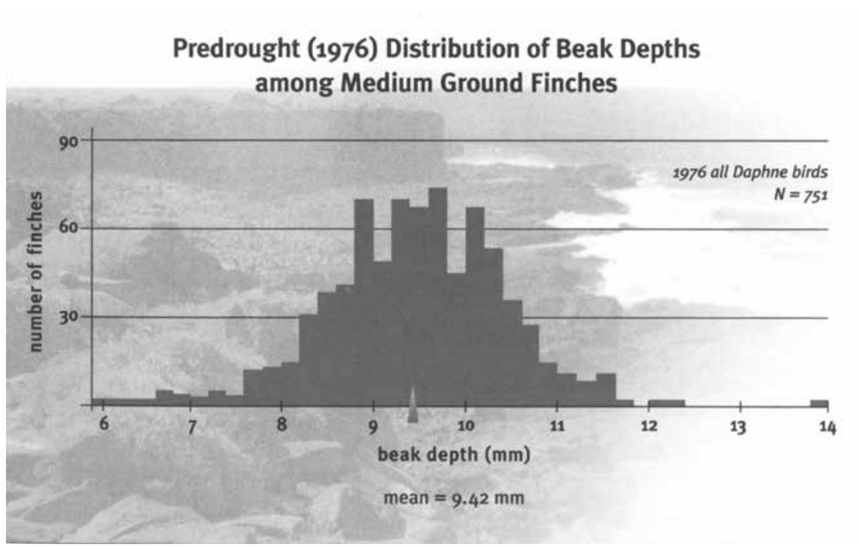
Exploration	Description of the *Explore* Phase
Students investigate initial ideas about evolution in interesting and meaningful contexts.	This phase provides students with a common base of experiences within which they identify and begin developing concepts, practices, abilities, and skills. Students actively explore the contextual situation through investigations, reading, web searches, and discourse with peers.

This phase of instruction had several activities that began with slides of the Galápagos Islands. During the slides, Ms. Lopez pointed out the climate and geological and human history. The slides helpfully included iguanas and birds. Ms. Lopez mentioned Charles Darwin's 1835 visit to the Galápagos Islands, but she did not discuss it in detail. The slides presented an opportunity to discuss scientific study in the islands, and Ms. Lopez pointed out several important characteristics of scientific study. The discussion included that science is a way of knowing; that scientists use models, themes, laws, mechanisms, and theories to explain natural phenomena; and that scientific knowledge assumes an order and consistency in nature. Ms. Lopez concluded the lesson with an assignment to read some background on the species of finches in the Galápagos and an excerpt from Jonathan Weiner's 1994 book *The Beak of the Finch.*

The next day, students were presented with actual data on the beak depth and tarsus (foot bone) length of the medium ground finch. Students recorded the data. Partway through the lesson, Ms. Lopez explained that data are easier to interpret when they are summarized and quantitative data are summarized using simple statistics. Ms. Lopez then explained use of *N* to represent the number of observations in a sample, the average or mean, and the range in data. The students determined these values for the beaks and tarsus of medium ground finches. After the analysis of beak depths and tarsus length, the students were asked to summarize their numerical data in graphic form and answer questions that required interpreting their data. Ms. Lopez asked, "Do the individual medium ground finches' beaks and tarsus vary? Are these variations *within* or *among* species?" The class ended with a question the students should consider as homework: How could the variation in beak depths help or harm the medium ground finches? Students also were assigned another section of *The Beak of the Finch* to read. The section described the fieldwork of Peter and Rosemary Grant as they measured various features of ground finches, including beak depths and tarsus lengths. The Grants also used specially engineered tools to measure the seeds eaten by the finches.

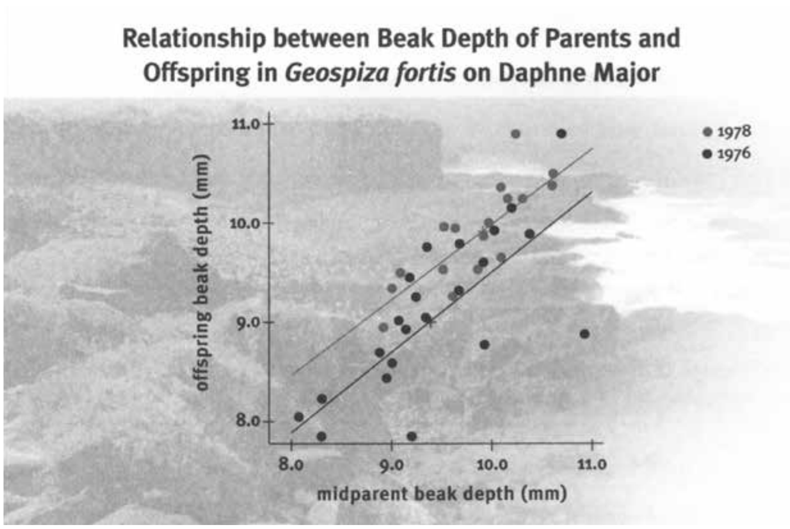
At the beginning of class the next day, groups of students received two graphic presentations of results from research on ground finches (see Figures 7.2 and 7.3).

FIGURE 7.2. SUMMARY OF PREDROUGHT (1976) DISTRIBUTION OF BEAK DEPTHS AMONG MEDIUM GROUND FINCHES



Source: Galápagos: An Inquiry Into Biological Evolution (BSCS 2004).

FIGURE 7.3. RELATIONSHIP BETWEEN BEAK DEPTH OF PARENTS AND OFFSPRING IN GEOSPIZA FORTIS ON DAPHNE MAJOR



Source: Galápagos: An Inquiry Into Biological Evolution (BSCS 2004).

Students were told that Figure 7.2 summarizes measurements of beak depth from 751 birds. They were to compare the variations in this sample with their smaller sample. The teacher asked, "How do any variations compare? What might explain any differences in mean values?" The student groups formulated tentative answers to these questions.

Ms. Lopez directed attention to the second graph. She explained that in the previous activities, the students had explored variation among medium ground finches; traits such as beak depth vary within a population because of genetic or environmental reasons. She explained the different reasons for variations and the fact that geneticists can calculate a numerical value called heritability as an estimate of how much of a variation in a trait is due to genetics. The second graph presents results of samples of beak depth taken at two different times—1976 and 1978—and the slope of the two lines shows a high value for heritability. Ms. Lopez told the students that the results were from the research team headed by the Grants, who they had read about in *The Beak of the Finch.*

The next class began with a review. Ms. Lopez summarized the following for the students: "In your investigations, you have made observations and measurements; you have analyzed and interpreted data; and you have obtained, evaluated, and communicated information about the results of others' scientific investigations and about the practices of science."

Explaining the Concepts and Practices

TABLE 7.4. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE EXPLAIN PHASE

Explanation	Description of the *Explain* Phase
Students analyze the explorations. Their understanding is clarified and modified through the introduction of scientific concepts and practices.	This phase focuses on developing an explanation for the situation students have been exploring. They verbalize their conceptual understanding and demonstrate their skills or abilities. Teachers introduce formal labels, definitions, and explanations for concepts, processes, skills, or abilities.

The exploration ended with a challenge for student groups: How could they explain the change in average beak depth of the population of medium ground finches? The students had to use their prior experiences to explain the relationship between environmental change and a population response.

This new phase of instruction centers on scientific explanations. It began when Ms. Lopez asked student groups for their analysis and explanation of the change in average beak depth. As the students proposed their explanations, Ms. Lopez detected a range in understandings of the scientific practices, disciplinary core ideas, and crosscutting concepts. She used several different means to explain the activities and introduce the concepts of Biological Evolution: Unity and Diversity.

In this phase of instruction, Ms. Lopez used the *EVO* DVD on "What Is Evolution?" Before the video, she asks the students to answer the question, "What is evolution?" After several students shared their answers, Ms. Lopez said, "Let's see how scientists answer the question." The *EVO* DVD introduced initial explanations by distinguished scientists. The general theme of their answers is descent from a common ancestor." A discussion of differences between the students' and scientists' explanations ended the class.

"Who was Charles Darwin?" was the question at the beginning of the next class. Again, the *EVO* DVD introduced the Galápagos and provided a brief history of Darwin's experiences as a naturalist and the historical development of the idea of evolution. After some discussion, Ms. Lopez turned attention back to the earlier lessons on the beaks of medium ground finches on Daphne Major.

Ms. Lopez reviewed the prior activities and explained that the students identified four key conditions that applied to changes in the beaks of the finch populations between 1976 and 1978. She described the conditions:

> There is variation in traits such as beak depth among individuals. … Second,

> there is a change in local environmental conditions, drought for example, that limit the number of individuals able to survive and reproduce. … Third, the population includes some individuals with traits—genetic variations—better adapted to the changing conditions. … Finally, the trait variations can be inherited between generations.

She continued, "The first three conditions together result in greater survival and reproductive success of individuals with adaptive traits. … This is *natural selection*." She then had the students read a short quote by Charles Darwin. Ms. Lopez first discussed the fact that Darwin devoted a portion of the first chapter in *On the Origin of Species* to a discussion of artificial selection (human breeding of plants and animals). Darwin used the features of domestic breeding as his model for discussing and defining the process of natural selection.

Students then read and discussed the quotation where Darwin introduced the idea of natural selection:

> Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle of life, should sometimes occur in the course of thousands of generations? If such do occur, can we doubt (remembering that many more individuals are born than can possible survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and of procreating their kind? On the other hand, we may feel sure that any variation in the least degree injurious would be rigidly destroyed. This preservation of favourable variations and the rejection of injurious variation, I call Natural Selection. (Darwin [1859] 1964, pp. 80–81)

As part of the discussion of this quotation, Ms. Lopez directed the students to pay close attention to Darwin's logic and reasoning. The lesson continued by showing the "What Is Natural Selection?" section on the *EVO* DVD. The students were quite interested because there were different examples of natural selection and a brief discussion with Rosemary and Peter Grant of the changes in the beaks of finches investigated between 1976 and 1978. The class concluded with an assignment to read a section on natural selection from *The Beak of the Finch*.

Ms. Lopez began the next day by directing attention to the nature of science. She made the transition by noting that Darwin's theory of biological evolution had been introduced and it was important to discuss how science "works" and the characteristics of scientific explanations and theories. She asked the students to tell what they knew about how scientists explain objects, organisms, and events in the world. Responses from the students varied widely. They used responses such as "they use facts," "theories come from observations," and "scientists try to predict the future."

Ms. Lopez continued:

> Let me use some of the ideas you mentioned to explain more about science. We can use some of your investigations as examples. One of the first things you should know about scientific explanations is that they are based on empirical evidence. Empirical evidence is information collected directly through our five senses—sight, hearing, smell, touch, and taste. In these days, technology usually extends our senses. The use of telescopes, microscopes, and scales are examples of technologies scientists use to extend human senses. In your earlier studies, the fact that scientists saw and measured the beaks of finches provided empirical evidence. Scientists have different ideas about the use of empirical evidence—for example, scientific explanations are stronger if scientists use multiple independent lines of evidence to support a single explanation.

She continued her explanation of the nature of science and the role of technology:

> To summarize, the scientific explanation, must be logical and consistent with observational and experimental evidence, make accurate predictions, be open to criticism and modification, and be made known to other scientists. That is the reason scientists make presentations and publish their investigations and experiments, making the methods, procedures, data, and conclusions public.
>
> Observations that have been repeatedly verified by others are accepted as facts. A fact is a generally agreed-upon observation about the natural world that is based on the best technology available. As technology improves, facts and scientific explanations may change because, for example, a new technology may result in more accurate observations. This leads to a second important characteristic. Scientific knowledge is open to revision in light of new evidence. A scientific explanation is subject to change and improvement if scientists have new evidence.
>
> Some scientific explanations are so thoroughly tested and the explanations predict so consistently that they are given a special name. They are called theories. In science, a theory is a comprehensive explanation about some aspect of the world that has been extensively tested and widely accepted as the explanation with the most evidence and best predictive power.
>
> Even when a scientific theory is widely accepted, it is still considered open to revision. This means that it is still subject to continued study and refinement as new evidence helps scientists improve their understanding. Most major ideas in science are supported by a lot of evidence, so they are not likely to change greatly in the future. The scientific explanation

for biological evolution is one such theory. We will learn more about this theory in the following lessons.

Elaborating on the Concepts and Practices

TABLE 7.5. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE ELABORATE PHASE

Elaboration	Description of the *Elaborate* Phase
Students have opportunities to expand and apply their understanding of the concepts within new contexts and situations.	These lessons extend students' conceptual understanding through opportunities for students 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.

The class began with a brief review of the evidence of common ancestry and diversity and natural selection as the mechanism for evolution and adaptation.

Ms. Lopez continued by asking the students, "When you hear the word *evolution*, what do you understand about the process and what do you think?" Several students responded, "Humans evolved from apes." Ms. Lopez asked several questions: "Did humans evolve from apes, or do modern apes and humans have a common ancestor? Do you understand the difference between these two questions?" She continued by telling the students that day's activity would help them understand the similarities and differences in the characteristics of humans and apes.

Each student received a table with the characteristics of apes and humans. Characteristics on the table included morphological features such as posture, length of arms and legs, feet, teeth, skull brain size, and age of puberty. After taking time to study the features, the students used the data to propose connections between humans and apes. This activity ended with Ms. Lopez introducing the idea that morphological structures may be similar because they serve the same functions or because they were inherited from a common ancestor. A slideshow that displayed a morphological tree illustrated the degree of morphological similarity among organisms used (see Figure 7.4, p. 98).

The morphological tree showed relationships to several organisms but not to gorillas, chimpanzees, and humans. Students were asked to work in groups of three to use the diagram to propose three possible ways that the "tree" could show connection to gorillas, chimpanzees, and humans. Their results are displayed in Figure 7.5 (p. 98).

FIGURE 7.4. EVOLUTIONARY RELATIONSHIPS BASED ON MORPHOLOGICAL CHARACTERISTICS

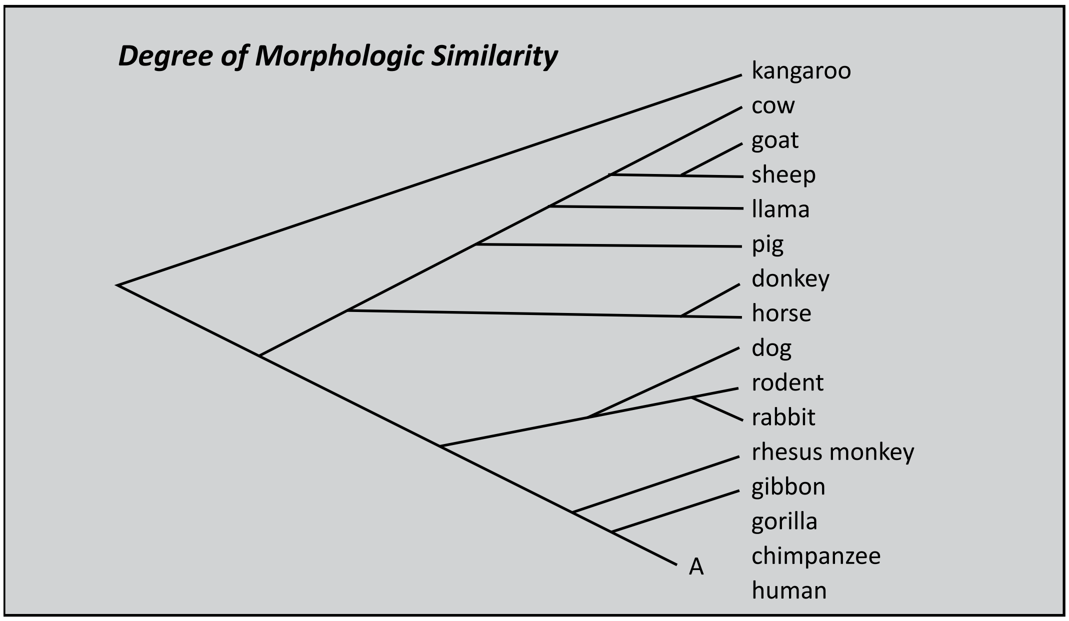
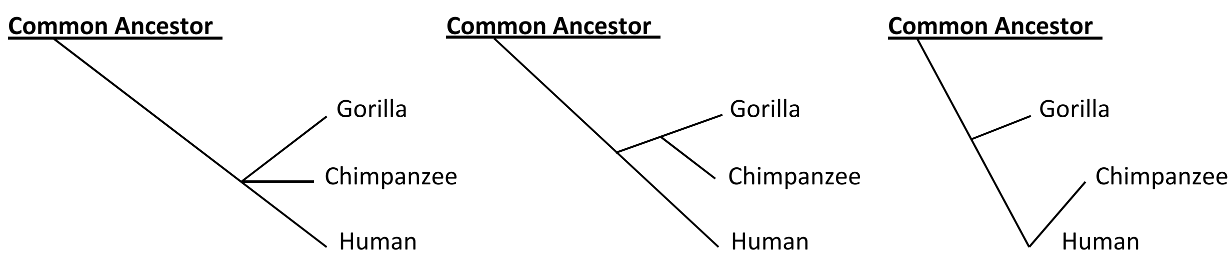


FIGURE 7.5. PROPOSED RELATIONSHIPS FROM COMMON ANCESTOR TO GORILLA, CHIMPANZEE, AND HUMAN



Ms. Lopez began class by telling the students that modern technologies allow biologists to compare the DNA codes for certain proteins and use those comparisons to predict how closely organisms are related.

Ms. Lopez told the students, "You ended the last class by preparing three possible ways to complete the tree and show the relationships among gorillas, chimpanzees, human beings, and a common ancestor." She continued by telling the students that they would use models of these techniques to determine which of their proposed connections is supported by data.

Working in groups of four, the students synthesized model strands of DNA in which colored paper clips represented one of the four bases of DNA. All students used the following specifications for their models.

Paper Clips	DNA Base	Symbol
Black	Adenine	(A)
White	Thymine	(T)
Green	Guanine	(G)
Red	Cytosine	(C)

Each group member synthesized a DNA sequence according to specifications. After synthesizing the strands (about 35 paper clips), each student laid out the sequence in a specified way. The other three group members displayed their sequences in a similar manner.

Ms. Lopez explained that each of the four students had a different DNA sequence—one for human beings, chimpanzees, gorillas, and a common ancestor—and that the sequence was a code for hemoglobin protein for the respective organisms.

Ms. Lopez pointed out that the strand for the common ancestor was hypothetical but the other three sequences of their models represented actual sequences of DNA. The students then compared the different strands for the human DNA, the gorilla DNA, and the chimpanzee DNA. The results indicated that humans are more closely related to the chimpanzee than they are to the gorilla by matching base with base (paper clip by paper clip). In the comparison, students counted the number of bases that were not the same and recorded the data in a table.

In the next phase of instruction, the students compared, one at a time, the common ancestor DNA to all three of the other samples. In a series of evaluation questions, the students used their observations to make three conclusions: Gorilla DNA is most similar to the common ancestor, humans and apes have a common ancestor, and chimpanzees and humans share a common ancestor.

After this discussion, Ms. Lopez asked students to determine the kinds of data that would provide further support for their original proposal about the relationships among organisms. Students responded that additional DNA sequence, the fossil record, and comparison of anatomical features would provide further support.

At the conclusion of class, Ms. Lopez placed the activity in a larger context. She began with the historical context:

> In 1859, Charles Darwin proposed a set of ideas that included organisms of different kinds descended from a common ancestor (common descent); species multiply over time (speciation); evolution occurs through gradual changes in a population (gradualism); and competition among species for limited resources leads to differential survival and reproduction (natural selection). The activity you just completed was about common descent.

> In Darwin's time, the idea of common descent was revolutionary because it introduced the concept of gradual evolution based on natural mechanisms. The idea of common descent also replaced a model of straight-line evolution with a branching model based on a single origin of life and subsequent series of changes—branching—into different species.

Ms. Lopez continued by pointing out the intellectual and creative leap from observations and evidence to scientific explanations:

> During the voyage of the HMS *Beagle*, Darwin observed that three species of mockingbirds on the Galápagos Islands must have some relationship to a single species of mockingbird on the South American mainland. This was the great intellectual step from observations to explanations. If a species could produce multiple descendent species, then it was but a series of logical steps to the inferences that all birds, all vertebrates, and so on had common ancestors.
>
> Common descent has become a conceptual backbone for evolutionary biology because common descent has significant explanatory power. Immediately, the idea found supporting evidence in comparative anatomy, comparative embryology, systematics, and biogeography. Recently, molecular biology has provided further support, as you discovered in this activity.

Finally, Ms. Lopez pointed out the use of a model in the activity and in science. She told the students:

> Models are representations of objects, organisms, events, or smaller components of these categories. Models help scientists and engineers understand how things work. They may have different forms such as physical objects, plans, maps, mental constructs, mathematical equations, analogies, and computer simulations.
>
> While there are many different types of models that scientists use, the models have certain characteristics. They have explanatory power, can predict changes in systems, are based on data, are understandable by other scientists, and embody theoretical constructs.

Ms. Lopez continued the explanation by changing the topic to the nature of science: "In this unit, you have been studying the theory of biological evolution." So, I ask, what is a theory? Students presented several different answers, including "the way someone explains something," "an idea," "how things work," "what has proof," "the facts," and "a guess about something."

Ms. Lopez explained:

> As we discussed in an earlier lesson, in science the word *theory* has a specific meaning. A scientific theory is a substantiated explanation of some aspect of the natural world. It is based on a body of facts that have been repeatedly confirmed with empirical evidence, and the theory is generally accepted by the scientific community.
>
> To nonscientists, theory sometimes refers to a guess, general idea, or personal explanation about something. The main difference is that for nonscientists, a theory has little or no empirical evidence to support it. For example, the germ theory of disease explains that certain infectious diseases are caused by microorganisms. Scientists began collecting supporting evidence for this explanation of disease during the 1800s. Now most scientists and nonscientists accept the germ theory as the best supported explanation for infectious diseases.
>
> The germ theory of disease provides a powerful explanation for certain types of illnesses. It has been verified many times by many scientists. So why is it called a theory? It is called a theory because it is *not* in doubt. By calling this explanation for infectious disease a theory, scientists are saying that it is supported by substantial evidence and widely accepted within the scientific community.
>
> The theory of biological evolution has the same broad support and confidence in the scientific community. That evolution in fact happens is clear from the combined evidence of geology and paleontology, comparative anatomy, physiology and biochemistry, embryology, biogeography, taxonomy, and molecular biology. That natural selection is a major way in which evolution happens also is supported by empirical evidence from laboratory experiments and in field investigations."

"One of the important activities of scientists is the growth of knowledge in their area of study. Scientists have to differentiate facts from propositions, make inferences, and use logic and evidence to develop strong explanations about the natural world."

Ms. Lopez continued, "The early formulation and subsequent development of the theory of biological evolution gives a conceptual structure for empirical knowledge, shows logical relationships among the facts and inferences of a theory, and shows where the critical role of human imagination enters the processes of science." Your prior activities began with a set a postulates and then continually encountered questions about evidence supporting the postulates, the development of explanation, the ability to predict, and the lines of reasoning that connect the various lines of evidence, explanations, and predictions.

Here is something that we can analyze to get a sense of how theories are developed and stated. In *One Long Argument* (1991), Ernst Mayr provides an example of the relationship between empirical observations (facts) and the inferences that form a vital aspect for the scientific endeavor. Figure 7.6 presents an example of the logic reasoning and imagination that go into formulating connections between evidence and scientific explanations.

In groups of three, the students were directed to review Figure 7.6 and describe the places where they thought there were statements of fact, where there were inferences, and where their study of the beaks of medium ground finches actually were examples of the statements.

FIGURE 7.6. EXAMPLE OF THE RELATIONSHIP BETWEEN EMPIRICAL OBSERVATIONS (FACTS) AND INFERENCES

Darwin's Theory of Evolution by Natural Selection

1: All species have great potential to produce large numbers of offspring. Their population size would increase exponentially if all individuals that are born survived and reproduced successfully.
2: Except for seasonal fluctuations, most populations are normally stable in size.
3: Natural resources are limited, and in a stable environment they remain relatively constant.

> **1:** Because more individuals are produced than the available resources can support, and the population size remains stable, there must be a struggle for existence among the individuals of a population. This results in the survival of only a part (often a very small part) of the offspring of each generation.

4: No two individuals in a population of organisms are exactly the same; rather, each population displays enormous variation in characteristics.
5: Much of this variation can be inherited.

> **2:** Survival in the struggle for existence is not random but depends in part on the characteristics that the surviving individuals inherited. This unequal survival is a process of natural selection that favors individuals with characteristics that best fit them in their environment.
>
> **3:** Through many generations, this process of natural selection will lead to a continuing, gradual change in populations—that is, to evolution and the production of new species.

Note: Based on a description by Mayr (1991).

For the concluding section of the *elaborate* phase and the instructional sequence, the students participated in a scientific summit on evolution. They were to work in pairs for the study and produce both a written report and a PowerPoint presentation. The teacher introduced the general topic: Relationships Between the Environmental Changes, Natural Selection, and Adaptation.

The teacher added that students were to investigate and report on a specific example of the general topic. Some of the specific examples could include the following:

- Antibiotic resistance
- Invasive species
- Use of pesticides
- Superbugs
- Pine bark beetle
- Florida panther
- Mammals' susceptibility to extinction

Evaluating the Concepts and Practices

TABLE 7.6. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: THE EVALUATE PHASE

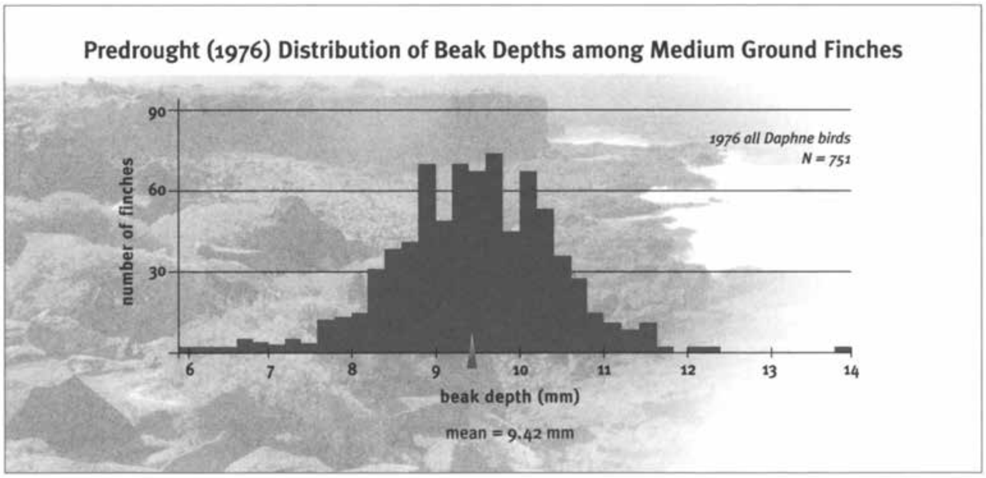
Evaluation	Description of the *Evaluate* Phase
Students assess their understanding of the concepts and practices, and teachers have the opportunity to assess student learning.	This phase emphasizes students assessing their understanding and abilities and provides opportunities for teachers to evaluate students' understanding of concepts and development of goals identified in learning outcomes.

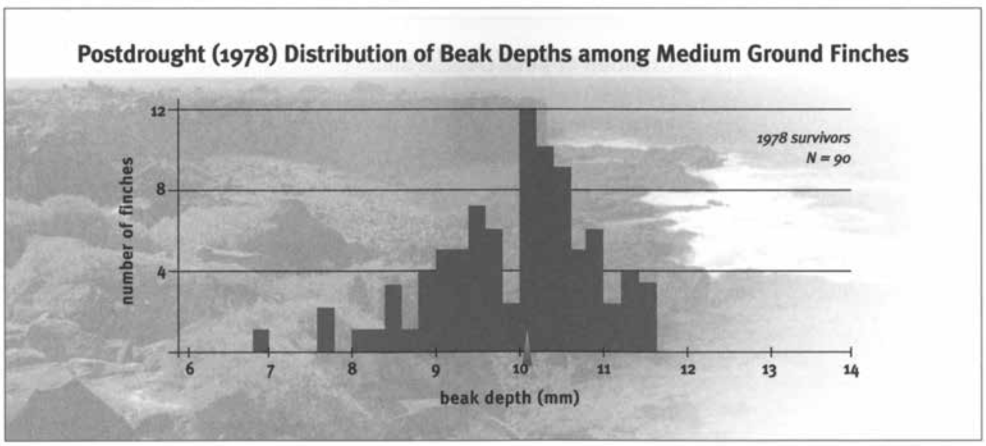
Overview

In this first assessment, designed for performance expectations HS-LS4-2 and HS-LS4-4, students are given evidence for natural selection. They are then asked to construct an explanation that uses natural selection as the mechanism for adaptation of populations—evolution.

QUESTION 1

Between 1976 and 1978, researchers Peter and Rosemary Grant documented a drought that resulted in a mean change in the average beak depth of medium ground finches on one Galápagos island. The change is displayed in the following graphs (p. 104).





Source: BSCS 2004.

Using evidence from the graphs, first explain what the graphs show. Second, use the evidence from the graphs to explain a connection between environmental change and the change in medium ground finches.

Explanation

SCORING/Question 1

Full credit
The graphs show that the mean beak depth increased as a result of the drought. The larger beak depth provided an apparent selective advantage. Drought presumably results in selection pressures that make plants with harder seed coating (and thus less likely to dry out) more likely to survive, which results in a selective advantage for birds that have beaks with greater depth because those types of beaks are better able to crack their harder seeds open.

Students also should differentiate between the process of natural selection that requires variation of traits among individuals in a population, the heritability of those traits, and environmental conditions that limit numbers of individuals able to survive and reproduce.

Second, students should point out the time and multiple generations involved in the species adapting from one set of environmental conditions to a new set of conditions.

In this second series of items, designed for performance expectations HS-LS4-3 and HS-LS4-5, students are presented with original evidence supporting the processes of natural selection. Students apply statistical results as the basis for constructing explanations of natural selection and biological evolution.

QUESTION 2

Between 1976 and 1978, there was a drought on the Galápagos Island Daphne Major. The drought included a lack of rainfall, an abundance of some seeds, and a scarcity of other seeds on the island. The scientists Peter and Rosemary Grant collected data on the beak depths of medium ground finches before and after the drought. The prior figures present their predrought and postdrought results.

Based on the two graphs, how did the average beak depths of the medium ground finch change between 1976 and 1978? Provide a brief answer.

SCORING/Question 2

Full credit
The average beak depth increased.

No credit
Other responses or no response.

QUESTION 3

Do the results of the research by Peter and Rosemary Grant support the following explanation(s) based on the data displayed in the graphs?

Organisms with advantageous heritable traits tend to increase in proportion to organisms lacking the trait. YES/NO
Organisms with advantageous heritable traits tend to decrease in proportion to organisms lacking the trait. YES/NO
Organisms with advantageous heritable traits are not affected in proportion to organisms lacking the trait. YES/NO

SCORING/Question 3

Full credit
YES, NO, NO (in that order)

No credit
Other responses, or no response.

QUESTION 4

In general, does the evidence in the graphs support the claim that changes in environmental conditions may result in

- increases in an individual trait within a species? YES/NO
- emergence of a new species? YES/NO
- extinction of other species? YES/NO
- increases in the number of individuals of some species? YES/NO

SCORING/Question 4

Full credit
YES, NO, NO, NO (in that order)

No credit
Other responses, or no response.

QUESTION 5

In the situation above, the cause for the changes in species is due to a change in the environment, such as drought, deforestation, or a long-term change in average temperature.

Describe evidence that would support the three claims in Question 4.

SCORING/Question 5

Full credit
Students may refer to the graphs and make a quantitative statement such as "The numbers

of individuals of a species with a specific trait may increase over several generations" or "In time the numbers of a species may decrease or become extinct." The emphasis should be on the use of evidence based on the effect, not the cause.

No credit
Answers that do not include evidence based on the effect, or discussion of the cause without reference to the effect.

QUESTION 6

Describe evidence other than that in the graphs that would support the claim that environmental changes may result in the emergence of a new species.

SCORING/Question 6

Full credit
Students indicate that the environmental change (cause) may be so long term that a new and distinct species emerges as the original populations diverge in time and geography. The evidence may include numbers of individuals, heritable traits, and DNA.

No credit
Answers that do not use evidence such as phenotype or DNA. Focus should be on the effect, not causes.

QUESTION 7

How could environmental changes eventually lead to the extinction of this species of finches?

SCORING/Question 7

Full credit
Students indicate that sometimes the environmental changes are so severe so quickly that species no longer survive and reproduce in the altered environment. In this case, the species has no opportunity to evolve; it becomes extinct. Students may use sedimentary rock formations and fossil evidence as the example.

No credit
Focus on the cause and not the effect of environmental change.

TABLE 7.7. SUMMARY OF TEACHING AND ASSESSMENT THAT SUPPORT THE *NEXT GENERATION SCIENCE STANDARDS* (HIGH SCHOOL)

NGSS-Based Performance Expectations	Teaching Strategies	Assessment Strategies
• Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential of a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. • Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. • Construct an explanation based on evidence for how natural selection leads to adaptation of populations. • Evaluate the evidence supporting claims that changes in environmental conditions may results in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.	**Engage** Students review pictures of different organisms and group the organisms by criteria they establish. Students then review graphs of the anatomy (e.g., "arms") of different organisms and attempt to identify the organisms' habitats. **Explore** Students review slides of the Galápagos Islands and are told of the climate, geology, and history. They are introduced to themes of scientific study. Students then review data on beak depth and tarsus length and are introduced to descriptive statistics. The class includes a question: How could variation in beak depth help or harm finches? This phase also includes an introduction to heritability. **EXPLAIN** This phase centers on scientific explanations. The concepts central to biological evolution are introduced using the *EVO* DVD. Students read and discuss Darwin's description of natural selection. **Elaborate** The teacher first reviews the common ancestry and diversity. Students examine morphological features of apes and humans. The lesson sequence progresses to use of a model to compare DNA codes for proteins and comparison of how closely organisms are related. Understandings of scientific theories are introduced. This phase of instructions concludes with students working in groups to prepare for presentations on different topics related to evolution.	**Evaluate** Students are given graphical evidence for natural selection. They are asked to construct an explanation that incorporates natural selection as the mechanism for the adaptation of populations over time. A second series of items presents students with original evidence supporting the process of natural selection. Students apply the statistical results to construct an explanation for biological evolution.

TABLE 7.8. SUMMARY OF THREE DIMENSIONS AND INTEGRATED SCIENCE SEQUENCE

5E Model Phase	Scientific and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engage	Analyzing and Interpreting Data (Background)	Evidence of Common Ancestry and Diversity (Background)	Patterns Science Knowledge Assumes Order and Consistency in Natural Systems (Background)
Explore	Analyzing and Interpreting Data Obtaining and Communicating Information (Foreground)	Connections to the Nature of Science Natural Selection: Adaptation (Background)	Patterns Cause and Effect (Background)
Explain	Connections to the Nature of Science (Foreground)	Natural Selection (Foreground)	Cause and Effect (Background)
Elaborate	Developing and Using Models (Foreground)	Evidence of Common Ancestry Diversity Adaptation (Foreground)	Cause and Effect (Foreground)
Evaluate	Construct and Explaining Use of Model Communicating Information Nature of Science (Foreground)	Evidence of Common Ancestry and Diversity Natural Selection: Adaptations (Foreground)	Patterns Cause and Effect (Foreground)

CONCLUSION

Implementing the *NGSS* does present significant challenges. There is the obvious and immediate challenge of classroom instruction. There also is the second long-term challenge of contributing to students' progressive understanding across the K–12 curriculum.

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CHAPTER 8
Beginning ASAP

We have the *Next Generation Science Standards* (*NGSS*)—now what? Does the current generation of curriculum materials align with the *NGSS*? Well, no. The general purpose of education standards is to reset the goals for education, then make curriculum programs, classroom instruction, and education assessments more coherent through processes of reform. So, many in the science education community are left with the question, "Where do we begin?" Which is followed by the imperative—and we have to begin as soon as possible (ASAP). In the context of this chapter, ASAP stands for both *as soon as possible* and *assessing standards to adapt programs*.

My answer to "Where do we begin?" is positive and productive: Begin by adapting current curriculum materials. This is neither the best nor the easiest solution, but one that is reasonable, prudent, and timely. With the release of the *NGSS*, few, if any, organizations have had time to develop new programs based on the standards. A second and even more critical reason for my recommendation involves budgets. Most states, districts, and schools lack the resources to replace entire science programs. In an era of constrained budgets, renewed priorities, and required curriculum changes, it seems to me the most immediate action is to adapt current lessons and curriculum units to accommodate the new science standards. Adapting current units may not be the most thorough response, but, it is reasonable, constructive, and doable.

Although budgets may not support adoption of a new program, one hopes that funds may be available for workshops to facilitate adaptation of current units and conduct professional development for science teachers.

This chapter has you assess the form and function of several science education standards to realize their application in science education. Not all standards are alike. There are, for example, content standards and assessment standards. This chapter progresses from an analysis of first-generation standards to the current *NGSS*. The purpose of the exercises in this chapter is to develop a deeper understanding of the forms and functions of science education standards before engaging in the analysis and adaptation of instructional materials.

EXAMINING THE FIRST-GENERATION SCIENCE EDUCATION STANDARDS

The best way to gain an understanding of standards for science education is to examine several. Take a few minutes and review the following standards from the *National Science Education Standards* (NRC 1996). After reading the standards (numbered 1 through 5), briefly answer the questions as best you can.

1. As a result of activities in grades K–4, all students should develop understanding of
   - The characteristics of organisms
   - Life cycles of organisms
   - Organisms and environments

   A. What are the strengths of this standard?

   B. What are the weaknesses of this standard?

   C. How would you approach teaching to this standard?

Following the standards stated above, there was a guide to the content standard that included fundamental concepts and principles that underlie the standard. One section included the following content:

Life Cycles of Organisms

- Plants and animals have life cycles that include being born, developing into adults, reproducing, and eventually dying. The details of this life cycle are different for different organisms.
- Plants and animals closely resemble their parents.
- Many characteristics of an organism are inherited from the parents of the organism, but other characteristics result from an individual's interactions with the environment. Inherited characteristics include the color of flowers and the number of limbs of an animal. Other features, such as the ability to ride a bicycle, are learned through interactions with the environment and cannot be passed on to the next generation.

2. What kinds of instructional experiences would be required for students to attain this standard?

   A. Direct instruction by the teacher

   B. Reading stories about the life cycles of organisms

   C. Full inquiries by students

   D. An inquiry guided by the teacher

   E. Other (please describe)

3. What kinds of assessments would be best to determine if students have attained the learning outcomes described in the standards?

   A. Pencil-and-paper test

   B. Performance-based assessment

C. Computer-based simulation
D. Science fair project
E. Other (please describe)

Here are two more standards.

4. Students should develop the following abilities of scientific inquiry.
   - Identify questions that can be answered through scientific investigations.
   - Design and conduct a scientific investigation.
   - Think critically and logically to make the relationships between evidence and explanations.
   - Communicate scientific procedures and explanations.

   A. What are the strengths of this standard?
   B. What are the weaknesses of this standard?
   C. What is required for students to achieve this standard?
   D. What evidence would you accept as an indication that students had met the standard?
5. By the end of grade 8, all students should understand that:
   - Different kinds of questions suggest different kinds of scientific investigations.
   - Current scientific knowledge and understanding guide scientific investigations.
   - Scientific explanations emphasize evidence; have logically consistent arguments; and use scientific principles, models, and theories.
   - Science advances through legitimate skepticism.

   A. What is the strength of this standard?
   B. What are the weaknesses of this standard?
   C. What is required for students to achieve this standard?
   D. What evidence would you accept as an indication that students had met the standard?

EXPLORING THE *NGSS*

We will continue with a careful and thorough examination of a critical component of the *NGSS*—the performance expectations. Table 8.1 displays a standard from *NGSS*. You will note that this standard also addresses life cycles of organisms. In *NGSS*, the performance expectations represent learning outcomes or the competencies students will be expected to demonstrate. Begin by reviewing Table 8.1.

TABLE 8.1. A PERFORMANCE EXPECTATION FOR ELEMENTARY SCHOOL LIFE SCIENCE WITH SUPPORTING CONTENT FROM THE FOUNDATION BOX AND CONNECTION BOX

3-LS1 From Molecules to Organisms: Structures and Processes

3-LS1 From Molecules to Organisms: Structures and Processes

Students who demonstrate understanding can:

3-LS1-1. Develop models to describe that organisms have unique and diverse life cycles but all have in common birth, growth, reproduction, and death. [Clarification Statement: Changes organisms go through during their life form a pattern.] [Assessment Boundary: Assessment of plant life cycles is limited to those of flowering plants. Assessment does not include details of human reproduction.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. ▪ Develop models to describe phenomena. (3-LS1-1) --- ***Connections to Nature of Science*** **Scientific Knowledge is Based on Empirical Evidence** ▪ Science findings are based on recognizing patterns. (3-LS1-1)	**LS1.B: Growth and Development of Organisms** ▪ Reproduction is essential to the continued existence of every kind of organism. Plants and animals have unique and diverse life cycles. (3-LS1-1)	**Patterns** ▪ Patterns of change can be used to make predictions. (3-LS1-1)

Connections to other DCIs in third grade: N/A

Articulation of DCIs across grade-levels: **MS.LS1.B** (3-LS1-1)

Common Core State Standards Connections:

ELA/Literacy –

RI.3.7	Use information gained from illustrations (e.g., maps, photographs) and the words in a text to demonstrate understanding of the text (e.g., where, when, why, and how key events occur). *(3-LS1-1)*
SL.3.5	Create engaging audio recordings of stories or poems that demonstrate fluid reading at an understandable pace; add visual displays when appropriate to emphasize or enhance certain facts or details. *(3-LS1-1)*

Mathematics –

MP.4	Model with mathematics. *(3-LS1-1)*
3.NBT	Number and Operations in Base Ten *(3-LS1-1)*
3.NF	Number and Operations—Fractions *(3-LS1-1)*

After a careful review of Table 8.1, answer the following questions.

1. Performance expectations integrate three dimensions—science and engineering practices, disciplinary core ideas, and crosscutting concepts. Look at Table 8.1 and identify each of the three dimensions of the performance expectations.
2. What does the 3-LS1-1 refer to?
3. Where are connections to the *Common Core State Standards*?
4. What does the scientific and engineering practice represent?
   A. Knowledge
   B. A skill or ability
   C. Both A and B
   D. None of the above
5. Is the scientific and engineering practice
   A. A learning outcome
   B. An instructional strategy

C. Both

D. Neither

6. As stated, what does the performance expectation require?

   A. A fact

   B. Understandings

   C. A skill

   D. An experience

   E. All of the above

7. As stated, what would count as evidence that the performance expectation had been attained?

   A. Knowing the disciplinary core idea

   B. Understanding the scientific and engineering practice

   C. Knowing the crosscutting concept

   D. All of the above

8. What kind of assessment would be required to determine if students have attained the learning outcomes described in Table 8.1?

   A. Paper-and-pencil test

   B. Teacher observation and evaluation

   C. Science fair project

   D. Computer-based assessment

   E. Performance-based assessment

9. Does the performance expectation suggest ideas and activities for classroom instruction?

   Yes (Please explain briefly.)

   No (Please explain briefly.)

10. How would you integrate the three dimensions of the performance expectation in classroom instruction? Please provide a brief explanation.

This exercise serves as a brief introduction to the standards. Now we continue with a clarification of different types of standards and the relationship between standards and classroom instruction.

EXPLAINING STANDARDS FOR SCIENCE EDUCATION

As you can see from the reviews in prior sections, standards for science education can engage questions about science curriculum and classroom instruction. Based on the introduction to science education standards, this is a good place to introduce a few central ideas and key terms that will contribute to adapting your curriculum and instruction based on the *NGSS*.

Content Standards

Content standards describe what students should know and be able to do as a result of their experiences in science classrooms. In general, content standards describe science concepts and practices. The series of *NSES* standards used in this chapter—recalling the first generation science education standards—are examples of content standards. They represented science concepts for life cycles of organisms and scientific inquiry—both abilities and understandings of inquiry. Although it might be obvious, it is worth noting that content standards are neither curriculum materials nor instructional strategies.

Performance Expectations

In the *NGSS*, the standards include descriptions of what students are expected achieve. In the *NGSS*, a performance expectation combines content for a scientific and engineering practice, disciplinary core idea, and crosscutting concept into a single statement. The foundation boxes beneath standards and performance expectations provide details and clarification of the content. As with content standards, performance expectations are neither curriculum materials nor instructional strategies. Because performance expectations clarify how students demonstrate what they have learned, these are the basis for assessments.

Standards and Curriculum

The performance expectations in *NGSS* are not a science curriculum. Curriculum includes the structure, organization, balance, and delivery of content in science classrooms. This is one way to explain and differentiate standards from curriculum. Standards are not science lessons, classes, courses of study, or school science programs. The performance expectations of *NGSS* can be organized with a variety of emphases and perspectives that result in different curricula. The performance expectations in *NGSS* are not intended to be used as curricula; instead, the scope, sequence, and coordination of concepts, practices, and ideas are left to those who design and implement school science programs and have ultimate responsibility for classroom instruction.

Designing science curricula presents the opportunity to integrate the three dimensions of *NGSS* and make connections to other educational priorities, such as the *Common Core State Standards* for English language arts and mathematics.

Standards and Curriculum Alignment

Individuals often express this topic as a question: Was a curriculum developed for the *NGSS*? Does a curriculum align with *NGSS*? The curriculum being alluded to is usually the current program in a school district or extant materials such as commercial science textbooks. These questions reveal several misconceptions. First, no science curriculum will align perfectly with standards, whether they are national, state, or local. The only thing that will match perfectly with *NGSS* is *NGSS*. Although this may seem obvious, some individuals require a complete alignment, or they decide that the curriculum under review is inadequate or incomplete. Second, curriculum materials should not be assessed using a single criterion, even if this is a standard. Especially in programs developed from a national perspective, decisions about the organization and presentation of materials must accommodate multiple criteria such as manageability and usability by teachers and learners, safety, and state or local adoption requirements (e.g., legal compliance). Third, it is not appropriate to use science content as the sole or principal criterion for judging the alignment of a science curriculum with *NGSS*. Some publishers claim that their textbooks and materials align with national standards. As it turns out, to say that curriculum materials are aligned often reveals a cursory and superficial set of connections between topics and themes, not a deeper association of science and engineering practices and concepts.

EXTENDING STANDARDS TO CURRICULUM AND INSTRUCTION

This final section extends your understanding of standards to the design and development of instructional materials. This process simulates the translation of *NGSS* into school curriculum and classroom instruction.

What is involved in using *NGSS* as the basis for instructional materials? This section has you begin by using a performance expectation and designing an instructional sequence that will help students attain the learning outcomes of the standard. (Please note that this is an initial translation and intentionally oversimplified.)

FROM AN ASSESSMENT TO CLASSROOM INSTRUCTION

The goal of this activity is to develop insights about the design and potential development of instructional materials based on *NGSS.* The activity begins with a review, analysis, and, preferably, completion of a formative assessment designed for a performance expectation from *NGSS.*

In the second part of the activity, you use the assessment to design an instructional sequence that provides students adequate and appropriate opportunities to learn the science and engineering practice, disciplinary core idea, and crosscutting concept described in the performance expectation.

Part I: Establishing Acceptable Learning Outcomes

Begin by reviewing and completing the following assessment. This is the first step in establishing the goals and acceptable learning outcomes for an integrated instructional sequence. The process is based on the use of backward design as described by Grant Wiggins and Jay McTighe in *Understanding by Design* (2005).

This assessment of a grade 4 performance expectation on energy is designed for the *evaluate* phase of the BSCS 5E Instructional Model. The assessment is performance based and includes four questions, each scored separately. Based on the four questions, the achievement levels may be described as advanced, proficient, basic, or below basic.

- At the advanced level, students demonstrate a deep understanding of all dimensions of the performance expectation. Students that get full credit on all four questions are advanced.
- Students at the proficient level demonstrate an understanding of the practice, core idea, and crosscutting concept at a level appropriate for grade 4. They score correctly on three out of four questions.
- Students at the basic level demonstrate a partial or beginner's understanding of the three dimensions. Students at the basic level score correctly on two out of four questions.
- Students scoring correctly on only one or no questions are below the basic level.

The performance-based assessment follows below.

TABLE 8.2. PERFORMANCE EXPECTATION

4-PS3 Energy

4-PS3 Energy		
Students who demonstrate understanding can: **4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.** [Assessment Boundary: Assessment does not include quantitative measurements of energy.]		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on K–2 experiences and progresses to include investigations that control variables and provide evidence to support explanations or design solutions. • Make observations to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution. (4-PS3-2)	**PS3.B: Conservation of Energy and Energy Transfer** • Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced. (4-PS3-2) • Light also transfers energy from place to place. (4-PS3-2) • Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy. (4-PS3-2)	**Energy and Matter** • Energy can be transferred in various ways and between objects. (4-PS3-2)

Students use simple materials to test their ideas and use observations from their tests to provide evidence that energy is transferred from one place to another or from one object to another by sound, light, heat, or electric current (disciplinary core idea). Students use their observations as evidence for an explanation (science and engineering practice) that energy can be transferred in various ways between objects (crosscutting concept).

Each student should have a small kit that includes the following items:

- Sheets of paper
- Balloons
- Paper clips
- Spoons
- Battery
- Rubber bands
- Small flashlight
- Pencil
- Small portable mirror
- String
- Plastic straw
- Ruler
- Sheet of aluminum foil
- Marbles
- Tape
- Resealable sandwich bags
- Bulb and short piece of copper wire

Tell the students that scientists ask questions about the world around them and search for evidence to support answers to their questions.

Use the materials in your kit to investigate a question about the transfer of energy from one place to another or one object to another.

QUESTION 1

Use the materials to answer this question: Can you demonstrate that heat is evidence that energy can be transferred from one place to another or from one object to another?

Use the space below to describe your investigation and the evidence that energy was transferred.

- In my investigation, I did the following:
- In my investigation, I observed that:
- The evidence that energy was transferred is:

QUESTION 2

Some individuals think that there is a connection between energy and sound. Can you provide evidence or the connection?

Describe your investigation that energy can be transferred into sound. What is the evidence that energy was transferred?

- The evidence I investigated is:
- My evidence of the interaction is:

QUESTION 3

Use the material to answer a question about light and the transfer of energy. Based on an investigation, answer the question below.

- How is lighting a bulb evidence that energy can be transferred?

QUESTION 4

Use the battery, bulb, wire, and any other materials for an investigation that lights the bulb.

This investigation is an example of:

- Energy can be transferred in different ways between objects. YES/NO
- Electric currents from batteries can transfer energy. YES/NO
- Holding the wire to the bulb is an observation that gives evidence of the transfer of energy. YES/NO

Part II: Designing an Integrated Instructional Sequence

Based on the assessment, you should have a clear idea of what students who demonstrate understandings of the performance expectation can and cannot do. Next, the challenge is to use those outcomes to design an instructional sequence that provides students opportunities to learn the valued outcomes.

This activity uses the 5E Instructional Model. That model is summarized here, with more elaborate descriptions provided prior to your proposed activities.

FIGURE 8.3. THE 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE

AN ENGAGE LESSON → EXPLORATION LESSON(S) → EXPLANATION LESSON(S) → ELABORATION LESSON(S) → EVALUATION LESSON(S)

Using the following descriptions of phases for the 5E Model, propose lessons for the instructional sequence.

TABLE 8.3. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: ENGAGING THE LEARNER

Engage	Description of the *Engage* Phase
Activities capture the students' attention, connect their thinking to the situation, and help them access current knowledge.	This sequence of lessons initiates the learning tasks. The activities should (1) activate prior knowledge and make connections between past and present learning experiences, and (2) anticipate activities and focus students' thinking on the learning outcomes of current activities. The learner should become mentally engaged in the concepts, practices, abilities, and skills of the curriculum unit.

An ENGAGING Lesson(s)

TABLE 8.4. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: EXPLORING THE CONCEPTS AND PRACTICES

Exploration	Description of the *Explore* Phase
Students investigate initial ideas and solutions in meaningful contexts.	This phase provides students with a common base of experiences within which they identify and begin developing concepts, practices, abilities, and skills. Students actively explore the contextual situation through investigations, reading, web searches, and discourse with peers.

An EXPLORATION Lesson(s)

TABLE 8.5. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: EXPLAINING THE CONCEPTS AND PRACTICES

Explanation	Description of the *Explain* Phase
Based on an analysis of the exploration, students develop an explanation for the concept and practices. Their understanding is clarified and modified through the teacher's descriptions and definitions.	This phase focuses on developing an explanation for the activities and situations students have been exploring. They verbalize their understanding of the concepts and practices. The teacher introduces formal labels, definitions, and explanations for concepts, practices, skills, and abilities.

An EXPLANATION Lesson(s)

TABLE 8.6. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: ELABORATING THE CONCEPTS AND PRACTICES

Elaboration	Description of the *Elaborate* Phase
Students have opportunities to expand and apply their understanding of the concepts within new contexts and situations.	These lessons extend students' conceptual understanding through opportunities for students 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.

An ELABORATION Lesson(s)

TABLE 8.7. BSCS 5E INSTRUCTIONAL MODEL AND AN INTEGRATED INSTRUCTIONAL SEQUENCE: EVALUATING THE CONCEPTS AND PRACTICES

Evaluation	Description of the *Evaluate* Phase
Students assess their understanding of the concepts, and teachers have the opportunity to assess student learning.	This phase emphasizes students assessing their understanding and abilities and provides opportunities for teachers to evaluate students' understanding of concepts and practices identified in performance expectations.

Describe any modifications or additions to the evaluation used as the basis for the instructional sequence.

EVALUATING THE INSTRUCTIONAL SEQUENCE

First, complete the summary of the instructional sequence (see Table 8.8, p. 126). Then answer the following questions.

- Did students have adequate and appropriate time and opportunity to develop an understanding of:
    - Science and Engineering Practice(s)?
    - Disciplinary Core Idea(s)?
    - Crosscutting Concept(s)?
- Was instruction aligned with the assessment?
- Did you make any connections to *Common Core State Standards* for English language arts or mathematics?

TABLE 8.8. A SUMMARY AND ANALYSIS OF LESSONS FOR *NGSS*

Phases of 5E Instructional Model	Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engage			
Explore			
Explain			
Elaborate			
Evaluate			

EVALUATING THE EXPERIENCE

The purpose here is not to evaluate the lesson(s). Think about the experience of designing a lesson based on the translation of a single performance expectation. Think about and answer these questions:

- What was the easiest part of the exercise?
- What was the most difficult issue you encountered?
- If you had to do this exercise again, what would you do differently?

SCORING/Question 1

Full credit
Student describes the materials and actions that, for example, produce *heat* and states that heat is the evidence that energy was transferred between the objects (e.g., student rubbed together two objects that resulted in heat as the evidence of energy transfer).

Partial credit
Student describes an activity (e.g., rubbing together two objects that result in heat) but does not make a logical statement about the role of observations and evidence to support the transfer of energy.

No credit
Student does something with materials but makes no connection to observations, evidence, or transfer of energy.

SCORING/Question 2

Full credit
Student uses materials to create a sound (e.g., snaps a rubber band and explains that vibrating objects produced sound as evidence of the transfer of energy).

Partial credit
Student describes an activity and states that sound was created but does not make the connection to the transfer of energy.

No credit
Other responses.

SCORING/Question 3

Full credit
Student may use the battery, bulb, and wire to indicate that lighting an object is evidence that energy was transferred from the battery to the bulb.

Partial credit
Student indicates that lighting an object is evidence of energy transfer but does not use the observation as evidence.

No credit
Student shows that light travels in a straight line, that light reflects, or other findings about light but does not indicate an understanding that energy is transferred or that observations produce data that serves as the basis for an explanation.

SCORING/Question 4

Full credit
YES, YES, NO (in that order)

Partial credit
2 correct and 1 wrong

No credit
3 wrong

CONCLUSION

This chapter introduced different forms of standards and clarified those relationships to curriculum and instruction. The chapter's activities set the stage for the adaptation or development of school programs and classroom practices that are the themes of the next two chapters.

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CHAPTER 9

Taking AIM

This chapter will help state science supervisors, district science coordinators, and school science teachers with the process of adapting instructional materials to accommodate the *Next Generation Science Standards* (*NGSS*). I wish to be clear about my recommendation to adapt current curriculum and instruction. The most adequate response would be to design entirely new school science programs and provide classroom teachers professional development based on these materials. The probability of this occurring within the next two or three years is very low. This said, the science education community must respond by taking aim and initiating actions. In the case of this chapter, AIM stands for *analyzing instructional materials*.

Chapter 8 emphasized the need to understand the form and function of the *NGSS*. Here, the discussion progresses to an understanding of instructional materials and how they can address the *NGSS*. The first sections use a general lesson, Understanding Scientific Investigations, to explore an overall analysis of instructional materials. The chapter continues to the process of adapting instructional materials based on *NGSS*.

Engaging the Analysis of Instructional Materials

Suppose you had to analyze instructional materials for possible adoption or adaptation. What qualities would be essential in your analysis of instructional materials? What would you look for? What would constitute the depth and breadth of your analysis? What would be the criteria used in your analysis? These are a few of the questions that may be included in an analysis of instructional materials.

Analyzing Instructional Materials (AIM): An Initial Exploration

We will begin with an exploration of a lesson that was not designed for *NGSS*. The purpose of this initial exploration is to develop an understanding of the form and function of instructional materials. Figure 9.1 (pp. 130–132) presents a science lesson narrative and describes several associated classroom activities. I have not included details about materials, equipment, schedule, or teacher background. This lesson is presented as an exploration of classroom instruction and an introduction to the analysis of instructional materials. Following the lesson, there are several questions as part of this exercise.

FIGURE 9.1. A SCIENCE LESSON FOR AIM

Understanding Scientific Investigations

(The following narrative is in the students' textbook.)

How do scientists investigate the world? They use telescopes, computers, and other instruments. All of the instruments you can think of were invented by scientists and engineers to make better observations and store and analyze information about the world. **Observations** can be firsthand experiences of objects, organisms or events in nature. Sometimes, however, things that happen in nature are too big, too small, too fast, or too slow for scientists to observe. Scientists and engineers have invented instruments to enable them to extend their senses and make accurate observations. Then they take their observations and interpret the meaning as they try to answer questions about nature. **Interpretations** are judgments about observations of objects, organisms, or events and explanations of them.

You may have observed, for example, that the Moon moves across the sky like the Sun, that plants and animals have life cycles, or that materials have different properties.

Before the next science class, make your own investigations of something that changes, something that stays the same, something that is alive, and something that is not alive.

What Is a Scientific Investigation?

Now that you have completed your own investigation, you are better prepared to answer the question, "What is a scientific investigation?" In your investigation, you attempted to judge or interpret the nature of the objects or organisms that changed. Your powers of observation were limited, and you had little evidence in making interpretations of what you observed. Despite this, you may have been quite accurate in describing the changes of objects or organisms.

Suppose that you wished to answer a more complicated question or solve a more complex problem than the one you investigated. How would you begin? The best way to begin would be to decide exactly what the question is or what problem you wish to solve. You might want to test an interpretation of a situation or idea about why something happens as it does. This is called a **hypothesis.** A hypothesis is based on observation and usually raises new questions or problems. The questions need to be tested and the additional information interpreted to determine whether or not the hypothesis is the best answer or proposed explanation.

When you begin a scientific investigation, you may find that you need information that your senses cannot provide, such as data from accurate measurements.

Figure 9.1 (*continued*)

Measurement includes methods of describing the characteristics of objects in numbers and usually requires the use of instruments. For example, instruments such as thermometers and metersticks enable you to express temperature as degrees and length in centimeters, respectively.

Scientists and engineers have designed many instruments so that they can measure such properties as hardness, brightness, distance, location, acidity, loudness, and speed, to name only a few. Instruments can increase the accuracy of measurement in an investigation. Instruments can also help you observe things that unaided human senses cannot detect. The telescope, for example, extends the sense of sight. Similarly, the microscope opens up the world of very small organisms. An instrument called a gravity meter makes possible the measurement of extremely small differences in the attraction of gravity on objects or organisms, and a Geiger counter measures atomic radiation.

In scientific investigations, the kind of observation scientists make depends on the nature of the question being investigated.

(The following is a student investigation.)

Investigating Mass, Volume, and Density

This activity uses many of the things done in scientific investigations. You will use instruments, make measurements, complete calculations, follow a mathematical formula, and present your own results.

Observe the two beakers. Each beaker contains a liquid and a solid. In one beaker, the liquid is water and the solid is a piece of granite. The other beaker contains a piece of granite, but the liquid is mercury. What is the difference between the mercury and the water that explains what you observe?

You can answer this question if you understand a property common to all matter—density. The **density** of a substance is its mass divided by its volume. The **mass** of a substance is the quantity of matter in it. The **volume** of a substance is the amount of space it occupies. Density is commonly expressed in terms of grams (mass) per cubic centimeter (volume). If you let the letter *D* stand for density, the letter *M* for mass, and the letter *V* for volume, density can be expressed by the formula

$$\mathbf{D = \frac{M}{V}}$$

This means that you can calculate the density (D) by dividing the mass (M) by the volume (V).

Suppose that an object has a mass (M) of 100 grams (g) and a volume (V) of 20 cubic centimeters (cm^3), what is its density (D) in grams per cubic centimeter (g/cm^3)?

Figure 9.1 (*continued*)

Part A: Determining Densities of Several Different Objects

Calculate the density (D) of each of the objects given to your group. To do this, you must know both the mass (M) and the volume (V) of the objects. Use a balance to determine the mass. Volume can be determined in many ways. After a discussion, decide with your group what method or methods you will use to determine volume. Determine and record the mass and volume of an object. Make a table to help you record and organize your data. Use the formula $\mathbf{D = \frac{M}{V}}$ to calculate the densities of the objects.

1. How does the difference in the shape of the metal objects influence their density?
2. What effect does the difference in the amount of modeling clay have on its density?
3. What is the density of wood?
4. Arrange your materials in order of decreasing density.
5. What is your calculated density of water?

Part B: Determining the Density of an Ice Cube

Now that you are familiar with density, you are ready for a challenge. Using the materials at your station, determine the approximate density of an ice cube.

1. What is the approximate density of your ice cube?
2. Explain how you determined this value.

Reporting Scientific Investigations

When scientists and engineers perform investigations, they make presentations and write reports similar to the one you will prepare for your investigations. If a scientist's report is published, it becomes useful to other scientists. His or her results can be tested by others and used to discover more about the question being investigated. Similarly, writing reports will help you organize your information and allow you to share it with your classmates.

In preparing reports, you should include the following: (1) the purpose—why you did the investigation; (2) procedure—what you did; and (3) the results—what you discovered.

Prepare a report on the density of ice.

First, review the instructional lesson provided in Figure 9.1. Answer the following questions based on your review and analysis:

- What are the learning outcomes?
- What types of experiences did the students have that would contribute to those learning outcomes?
- Were there any safety or hazard issues in the lesson?
- How would you improve the sequence of experiences that would effectively contribute to the learning outcomes?
- How were the learning outcomes assessed?
- How would you judge the value of this lesson for adaptation to provide learning experiences that accommodate the *NGSS*?

ANALYZING INSTRUCTIONAL MATERIALS: A SECOND EXPLORATION OF LESSONS FROM YOUR PROGRAM

As a second exploration, complete the same general analysis on a lesson or series of lessons that are part of your state or school science curriculum. Based on your analysis, answer the following questions:

- What are the learning outcomes?
- What types of experiences did the students have that would contribute to those learning outcomes?
- Were there any safety issues in the lesson?
- How would you improve the sequence of experiences that would effectively contribute to the learning outcomes?
- How were the learning outcomes assessed?
- How would you judge the value of this lesson for adaptation to provide learning experiences that accommodate the *NGSS*?

EXPLAINING CRITERIA FOR EVALUATING AND ADAPTING INSTRUCTIONAL MATERIALS TO ACCOMMODATE *NGSS*

Having completed a general exploration of instructional materials, we move on and develop an understanding of alignment between curriculum and teaching and *NGSS*. The goal is straightforward—to improve your science curriculum by adapting the materials based on *NGSS*. In the discussion that follows, the term *criteria* describes features or attributes that show the degree to which instructional materials align with *NGSS*. The discussion generally progresses from the simplest to the most complex attributes of science curriculum materials and instructional strategies.

In the simplest analysis, one can examine instructional materials to see if lessons or units integrate the three dimensions of content domains in *NGSS*. This approach, however, only gives an estimate of alignment. One must assume that science concepts (both disciplinary core ideas and crosscutting concepts) and practices from all three dimensions will not be in the instructional materials under review.

Probably a better way to analyze the potential for adapting materials is to identify what is or is not evident in comparing the materials and the performance expectation in *NGSS*. What about the science content that is in the performance expectations but not in the curriculum? For example, suppose the analysis reveals considerable alignment with subject matter in the Earth, physical, and life sciences but omissions concerning performance expectations on engineering and the nature of science. What about the omissions? This example points to the importance of a curriculum framework at the state and local levels and the need to consider K–12 school science programs. Such a framework gives a larger perspective on the science education program and thus identifies the opportunities to address omissions in other parts of the school science program.

Taking the analysis to another level, activities within your curriculum should be examined to determine how closely and explicitly they (1) already incorporate science and engineering practices, crosscutting concepts, and disciplinary core ideas in *NGSS*; (2) provide the time and opportunity for students to achieve the practices, concepts, and ideas in *NGSS*; (3) clarify a learning progression across the K–12 continuum; (4) address assessments that align with the three dimensions of content in *NGSS*; and (5) identify evidence of achievement for the learner and teacher so you know if a desired level of achievement has been attained.

Let me clarify one issue about *NGSS* and classroom instruction: It is essential to explicitly teach a concept or practice. If you want students to know that there are interdependent relationships in ecosystems and that changes in ecosystems can result from natural processes and human activity, then you have to include these concepts in the curriculum and teach them clearly and directly. If you want students to understand the practices and crosscutting concepts, you have to teach them. Students engaging in a hands-on activity may or may not get explicit opportunities for them to learn the practice, core idea, or crosscutting concept.

Also, time and opportunity to learn are critical criteria. Contemporary emphasis on constructive approaches to learning suggests that single lessons are probably inadequate approaches to teaching and learning because they do not provide learners with the time to engage in an idea, explore alternatives, discover different explanations, and construct more meaningful and scientifically accurate explanations. This process requires more time and multiple opportunities to develop understanding. The use of an instructional model in curriculum materials, or the potential of nonlinear approaches of educational technologies, usually accommodates the criteria of time and multiple opportunities to learn.

Another criterion combines opportunities to learn and instruction. Suppose a science textbook gives substantial emphasis to the memorization of the vocabulary of the disciplinary core ideas. What is wrong with this? The criterion has to do with the *NGSS* emphasis on the opportunities for students to engage in investigations and learn science and engineering practices as well as crosscutting concepts. There is this difference between memorizing vocabulary and the emphasis in *NGSS*.

Two criteria center on assessment. The first asks whether the curriculum includes assessment consistent with all three dimensions of content. The second requires a close look at assessment in curriculum materials to see if it defines acceptable levels of achievement. Do the instructional materials provide adequate information about acceptable goals of achievement and what students say, write, and communicate that indicates they have achieved the understandings of the standards?

Finally, can you identify possible connections to *Common Core State Standards* for English language arts and mathematics? This is an important issue that must be addressed in an evaluation of the potential for instructional materials to be adapted based on *NGSS*.

In final analysis, it is probably most productive to ask the question, "What do we have to do to adapt our curriculum to align with *NGSS*?" At this point, my recommendation should be clear: For most school districts, time and money will be best spent on improving the science curriculum through professional development that emphasizes adapting lessons and units.

USING *NGSS* CRITERIA TO ANALYZE INSTRUCTIONAL MATERIALS

The criteria in Table 9.1 (p. 136) brings us closer to understanding what will be required to adapt current materials so they align with the *NGSS*. In this section, you apply the criteria to determine the overall alignment of the sequence of activities in Understanding Scientific Investigations and proceed to identify specific changes that will adapt the lessons.

Return to the sequence of activities in Understanding Scientific Investigation (Figure 9.1, pp. 130–132) and complete an analysis using the criteria and questions in Table 9.1 (p. 136).

To conclude this section, you may apply this analysis to a sequence of lessons that are part of your state or local school science program. Such an analysis would likely be much more significant and essential as the first step toward adapting a unit of instruction.

EVALUATING POSSIBLE ACTIONS

This final section moves from the analysis of materials to the possible changes that will be required to adapt curriculum and teaching by integrating the competencies, content, and connections from *NGSS.*

TABLE 9.1. CRITERIA FOR ADAPTING INSTRUCTIONAL MATERIALS BASED ON THE *NGSS*

Criteria	Questions for the Analysis
• Identification of scientific and engineering practices • Crosscutting concepts • Disciplinary core and component ideas	• Do topics of the instructional materials match the three dimensions of *NGSS?* • Are standards explicitly represented in the materials?
• Explicit connections among practices, crosscutting concepts, and disciplinary core and component ideas	• Do activities include the practices, crosscutting concepts, and disciplinary core ideas of the standards? • Do activities include all the component ideas? • Are connections made with other topics, concepts, and practices?
• Time and opportunities to learn	• Does instruction include several activities on a topic? • Do students experience concepts before vocabulary is introduced? • Do students apply concepts and practices in different contexts?
• Appropriate and varied instruction	• Are different methods of instruction used? • Are students engaged in activities that emphasize all three dimensions?
• Appropriate and varied assessment	• Are opportunities provided for teachers to identify what students know and can do? • Are assessment strategies consistent with the performance expectations? • Are assessments comprehensive, coherent, and focused on the integration of core and component ideas, crosscutting concepts, and science and engineering practices?
• Potential connections to *Common Core State Standards* for English language arts and mathematics	• Where do the instructional materials present opportunities to make connections to the *Common Core State Standards*?

TABLE 9.2. EVALUATING POSSIBLE ADAPTATIONS OF UNDERSTANDING SCIENTIFIC INVESTIGATIONS

Instructional Sequence and Activities	Alignment With *NGSS*	Possible Adaptations to Increase Alignment With *NGSS*
Read the introduction and discuss observations and interpretation. Complete simple observational investigation.	• Reading the introduction may make connections to the *Common Core*, both reading and oral communication. • Simple observations could include both objects and organisms and an identifiable pattern.	• Increase emphasis on nonfiction reading. • Discuss how the students identify (ask) a question to guide their observations. Clarify the empirical bases to answering a scientific question.
What is a scientific investigation? Read the section and discuss the role of hypothesis and measurement.		
Investigating mass, volume and density Read the introduction and discuss the definition of density.		
Part A: Determining densities of several different objects Complete an investigation and calculate the density of several objects using the formula		
Part B: Determining the density of an ice cube Use materials and equipment to determine the density of an ice cube.		
Reporting scientific investigations Read and discuss writing scientific reports and results on investigations of density.		
Preparing a report on the density of ice Students prepare a report on their investigation.		

Begin by referring to the lesson in Figure 9.1 and outline in Table 9.2. Complete the required evaluation in Table 9.2. I have completed the first section in Table 9.2 to provide an example.

Using your instructional materials and the recommendations from this chapter, complete the evaluation suggested in Table 9.3.

You can use the criteria and the form in Table 9.3 to evaluate the potential of your state or local lesson for adaptation based on the *NGSS*.

TABLE 9.3. EVALUATING POSSIBLE ADAPTATIONS FOR YOUR INSTRUCTIONAL MATERIALS

Instructional Sequence and Activities	Alignment With *NGSS*	Possible Adaptions to Increase Alignment With *NGSS*
Lesson 1		
Lesson 2		
Lesson 3		
Lesson 4		
Lesson 5		
Lesson 6		
Lesson 7		
Lesson 8		

CONCLUSION

This chapter was designed to increase the depth and breadth of your understanding of instructional materials and to help you use that knowledge to evaluate possible actions to adapt the materials with *NGSS*. In conclusion, one has to ask what it will take to modify the instructional materials and support their implementation in school science programs. The reality is that modifying instructional materials will take expertise, time, and money. After the evaluation of instructional materials, one has to make a decision to move on and adapt—or not.

CHAPTER 10

Planning to ADAPT Materials for Classroom Instruction

In reality, making a decision to adapt instructional materials is not the best or easiest option. But almost immediately, you probably do not have other options. Modifying extant materials to better implement the *Next Generation Science Standards* (*NGSS*) rather than designing and developing new resources specifically for *NGSS* is not the ideal solution, but it is a real first step that will benefit the professional development of science teachers, classroom instruction, and student learning. Design, development, field-testing, revision, and production of new materials based on *NGSS* are long and costly. Adopting a commercially available program for K–12 also is costly. So let's go ahead and ADAPT!

Actually, I am using ADAPT as an acronym in two important ways. First, ADAPT refers to a process of *activating development for alignment of programs and teaching*—in brief, modifying current instructional materials to align with *NGSS*. Second, ADAPT can refer to *advancing development of appropriate plans for teachers*. Here, the reference I intend is use of the adapted instructional materials for the professional development.

Achieving the chapter's goals will be challenging.

- Identifying the degree to which current instructional materials (i.e., lessons, activities, and investigations) accommodate performance expectations from *NGSS*.
- Adapting those materials into a unit of instruction that is usable both for professional development and in classrooms.

AN ENGINEERING QUESTION: WHAT WILL IT TAKE TO ADAPT INSTRUCTIONAL MATERIALS SO THEY ARE *NGSS* FOCUSED?

Beginning in Chapter 8, discussions, activities, analysis, and recommendations have set the stage for this chapter. The short answer to the question that heads this section: It will take a clear understanding of the connections between current instructional materials and the *NGSS*. This is an essential first step.

To state an obvious but important point, when beginning with materials that were developed for a different set of standards, there is a limit to how completely they can be adapted to the *NGSS*. The task of taking action will require an analysis that answers this, a second question: What and where are the greatest opportunities to adapt current instructional materials so students will attain performance expectations described in the *NGSS*?

Four aspects of instructional materials form the basis for analysis. The first category for analysis is identifying the three dimensions of *NGSS*—scientific and engineering practices, disciplinary core ideas, and crosscutting concepts that are addressed. The second category to consider in analyzing instructional materials is the dynamic of instruction and the time and opportunity for students to attain the leaning outcomes. One stipulation is that the topics and activities contribute to performance expectations. A third requirement is for an integrated instructional sequence. Finally, both formative and summative assessments should be aligned with performance expectations and classroom instruction.

EXPLORING THE OPPORTUNITIES TO ADAPT: A PRELIMINARY SCREEN OF INSTRUCTIONAL MATERIALS

This preliminary screen of curriculum resources can be used for the full curriculum program or a small portion, such as several lessons or a unit of instruction. My advice is to begin small—for instance, with several lessons in an instructional sequence or short unit.

For a curriculum program, you will need the state or school curriculum framework and actual instructional materials—textbooks, units, and activities—that provide an adequate sampling of the elementary, middle, and high school curriculum.

For the preliminary screen, you should use a smaller portion of the program—for example, a unit of instruction. You also should review the *NGSS*, especially the science and engineering practices, disciplinary core ideas, and crosscutting concepts for the discipline and grade level you have identified as a potential unit to adapt. Chapter 2 in this book and the rubrics in Tables 10.1 through 10.9 later in this chapter may be helpful in the preliminary screen.

The aim here is to identify lessons or units of instruction that you think have the potential to be adapted. Remember, this is a preliminary screen. Later, I will describe a process for adapting instructional materials. After the preliminary screen, you will have an idea of what it will take to modify your curriculum unit.

For this preliminary screen, use the rubric in Table 10.1. Completing the rubric will provide an estimate of the potential for adapting the materials you have selected.

A PROCESS TO ADAPT INSTRUCTIONAL MATERIALS

Beginning in Chapter 8, the focus has been on the knowledge and skills required to adapt instructional materials. This is the point at which you and your team will have to just adapt. Depending on the team's knowledge and skills and the preliminary screen, you should select the activities and approaches from Chapters 8 and 9, design a process for modifying an instructional unit, and plan for professional development.

TABLE 10.1. A PRELIMINARY SCREEN FOR ALIGNMENT OF CURRICULUM RESOURCES WITH *NGSS*

NGSS	Alignment With *NGSS*	
Do the materials include Disciplinary Core Ideas (DCIs)?	Yes No	If yes, briefly describe.
Do the materials include Science and Engineering Practices (SEPs)?	Yes No	If yes, briefly describe.
Do the materials include Crosscutting Concepts (CCCs)?	Yes No	If yes, briefly describe.
Are the SEPs, DCIs, and CCCs integrated?	Yes No	If yes, briefly describe.
Do assessments include SEPs? DCIs? CCCs?	Yes No	If yes, briefly describe.
Are there opportunities to make connections to *Common Core State Standards*?	Yes No	If yes, briefly describe.
Does the grade level align with *NGSS?*	Yes No	If yes, briefly describe.
Other—appropriate for your state or district?	Yes No	If yes, briefly describe.

Here is a suggested process:

1. Review *A Framework for K–12 Science Education* (NRC 2012), *Next Generation Science Standards* (Achieve 2013), and *The NSTA Reader's Guide to the* Next Generation Science Standards (Pratt 2013).
2. Choose a small portion of your current curriculum that you identified in the preliminary screen. The lesson should align with a section of the *NGSS.*
3. Describe the degree to which the components of the selected portion of the curriculum can be modified and what it will take to modify those lessons. Complete the rubric in Table 10.2 (p. 143) for science and engineering practices; in Table 10.3 (pp. 144–145) for crosscutting

concepts; and in Table 10.4 (physical science, p. 146), Table 10.5 (life science, p. 147), or Table 10.6 (Earth and space science, p. 148) that are appropriate for the curriculum sequence you have identified.

4. Decide on an integrated instructional sequence. The instructional sequence should (1) provide for different forms of interaction among learners and between the teachers and learners; (2) allow for a variety of teaching strategies, such as investigations, cooperative groups, and use of technology; (3) integrate science and engineering practices, crosscutting concepts, and disciplinary core ideas within the instructional sequence; and (4) allow adequate time and opportunities for learners to formulate understandings of science and engineering practices, crosscutting concepts, and disciplinary core ideas.
5. Throughout this book, I have used the BSCS 5E Instructional Model as a practical example of an integrated instructional sequence. Integrating the three dimensions of the *NGSS* presents a challenge. Using an instructional model such as the 5Es will help with the question, "How do I integrate the three dimensions?" For this discussion, I will continue using the BSCS 5E Instruction Model. The model is summarized in Table 10.7 (p. 149).
6. Use the 5 E Instructional Model and backward design to begin adapting the selected instructional materials.
   - *Stage 1:* Clarify the desired outcomes (the standard that best aligns with the selected materials).
   - *Stage 2:* Determine acceptable evidence of learning (the performance expectations) and design the *evaluate* assessment activities for the 5E Model.
   - *Stage 3:* Adapt the lessons to accommodate the three dimensions of the selected performance expectations and the integrated instructional sequence of the 5E Model—*engage*, *explore*, *explain*, and *elaborate*. (Use the framework in Table 10.8, pp. 150–151).
7. Plan the process for actually adapting the materials (the *who*, *what*, *when*, *where*, *how*, and *cost*). The process likely will take some time. Use the framework in Table 10.9 (p. 152) to outline a schedule of activities.
8. A final and essential aspect of the process involves planning for and providing professional development. Much of the discussion in this book has described processes for the modification of instructional materials so they present curriculum and instruction that accommodate *NGSS*. If the modified instructional materials (a curriculum unit) will have an impact on student learning, the unit will have to be implemented in science classrooms. To be clear, the unit of instruction should be the basis for professional development.

TABLE 10.2. A RUBRIC FOR SCIENTIFIC AND ENGINEERING PRACTICES (SEPs)

DIMENSION Scientific and Engineering Practices (SEPs)	Instructional materials provide explicit and integral opportunities for students to attain an understanding of the practice. Recommendation: Only minor modification needed. Indicate unit or chapter and page. Add specific modification.	Instructional materials provide partial opportunity for students to attain an understanding of the practice. Recommendation: Major modification is needed, but possible. Indicate unit or chapter and page. Add specific modification.	Instructional materials do not provide opportunities for students to attain an understanding of the practice. Recommendation: Do not attempt to modify.
1. Asking questions (for science) and defining problems (for engineering)			
2. Developing and using models			
3. Planning and carrying out investigations			
4. Analyzing and interpreting data			
5. Using mathematics and computational thinking			
6. Constructing explanations (for science) and designing solutions (for engineering)			
7. Engaging in argument from evidence			
8. Obtaining, evaluating, and communicating information			

TABLE 10.3. A RUBRIC FOR CROSSCUTTING CONCEPTS (CCCS)

DIMENSION Crosscutting Concepts (CCCs)	Instructional materials provide explicit and integral opportunities for students to attain an understanding of the practice. Recommendation: Only minor modification needed. Indicate unit or chapter and page. Add specific modification.	Instructional materials provide partial opportunity for students to attain an understanding of the practice. Recommendation: Major modification is needed but possible. Indicate unit or chapter and page. Add specific modification.	Instructional materials do not provide opportunities for students to attain an understanding of the practice. Recommendation: Do not attempt to modify.
1. **Patterns.** Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying the patterns.			
2. **Cause and effect:** *Mechanisms and explanation.* Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships and the mechanisms by which they are mediated is a major activity of science.			

Table 10.3 (*continued*)

3. **Scale, proportion, and quantity.** In considering phenomena, it is critical to recognize what is relevant at different sizes, times, and energy scales and to recognize proportional relationships between different quantities as scales change.			
4. **Systems and system models.** Delimiting and defining the system under study and making a model of it are tools for developing understanding used throughout science and engineering.			
5. **Energy and matter: Flows, cycles, and conservation.** Tracking energy and matter flows into, out of, and within systems helps one understand a system's behavior.			
6. **Structure and function.** The way an object is shaped or structured determines many of its properties and functions.			
7. **Stability and change.** For both designed and natural systems, conditions of stability and what controls rates of change are critical elements to understand.			

TABLE 10.4. A RUBRIC FOR DISCIPLINARY CORE IDEAS: PHYSICAL SCIENCE

DIMENSION Disciplinary Core Ideas: Physical Science	Instructional materials provide explicit and integral opportunities for students to attain an understanding of the disciplinary core ideas. Recommendation: Only minor modification needed. Indicate unit or chapter and page. Add specific modification.	Instructional materials provide partial opportunity for students to attain an understanding of the disciplinary core ideas. Recommendation: Major modification is needed but possible. Indicate unit or chapter and page. Add specific modification.	Instructional materials do not provide opportunities for students to attain an understanding of the disciplinary core ideas. Recommendation: Do not attempt to modify.
Core Idea: Matter and Its Interactions A: Structure and Properties of Matter B: Chemical Reactions C: Nuclear Processes			
Core Idea: Motion and Stability: Forces and Interactions A: Forces and Motion B: Types of Interactions C: Stability and Instability in Physical Systems			
Core Idea: Energy A: Definitions of Energy B: Conservation of Energy and Energy Transfer C: Relationship Between Energy and Forces D: Energy in Chemical Processes and Everyday Life			
Core Idea: Waves and Their Applications in Technologies for Information Transfer A: Wave Properties B: Electromagnetic Radiation C: Information Technologies and Instrumentation			

TABLE 10.5. A RUBRIC FOR DISCIPLINARY CORE IDEAS: LIFE SCIENCES

DIMENSION Disciplinary Core Ideas: Life Science	Instructional materials provide explicit and integral opportunities for students to attain an understanding of the disciplinary core ideas. Recommendation: Only minor modification needed. Indicate unit or chapter and page. Add specific modification.	Instructional materials provide partial opportunity for students to attain an understanding of the disciplinary core ideas. Recommendation: Major modification is needed but possible. Indicate unit or chapter and page. Add specific modification.	Instructional materials do not provide opportunities for students to attain an understanding of the disciplinary core ideas. Recommendation: Do not attempt to modify.
Core Idea: From Molecules to Organisms: Structures and Processes A: Structure and Function B: Growth and Development of Organisms C: Organization for Matter and Energy Flow in Organisms D: Information Processing			
Core Idea: Ecosystems: Interactions, Energy, and Dynamics A: Interdependent Relationships in Ecosystems B: Cycles of Matter and Energy Transfer in Ecosystems C: Ecosystems Dynamics, Functioning, and Resilience D: Social Interactions and Group Behavior			
Core Idea: Heredity: Inheritance and Variation of Traits A: Inheritance of Traits B: Variation of Traits			
Core Idea: Biological Evolution: Unity and Diversity A: Evidence of Common Ancestry and Diversity B: Natural Selection C: Adaptation D: Biodiversity and Humans			

TABLE 10.6. A RUBRIC FOR DISCIPLINARY CORE IDEAS: EARTH AND SPACE SCIENCES

DIMENSION Disciplinary Core Ideas: Earth and Space Sciences	Instructional materials provide explicit and integral opportunities for students to attain an understanding of the disciplinary core ideas. Recommendation: Only minor modification needed. Indicate unit or chapter and page. Add specific modification.	Instructional materials provide partial opportunity for students to attain an understanding of the disciplinary core ideas. Recommendation: Major modification is needed but possible. Indicate unit or chapter and page. Add specific modification.	Instructional materials do not provide opportunities for students to attain an understanding of the disciplinary core ideas. Recommendation: Do not attempt to modify.
Core Idea: Earth's Place in the Universe A: The Universe and Its Stars B: Earth and the Solar System C: The History of Planet Earth			
Core Idea: Earth's Systems A: Earth Materials and Systems B: Plate Tectonics and Large-Scale System Interactions C: The Roles of Water in Earth's Surface Processes D: Weather and Climate E: Biogeology			
Core Idea: Earth and Human Activity A: Natural Resources B: Natural Hazards C: Human Impacts on Earth Systems D: Global Climate Change			

TABLE 10.7. AN INTEGRATED INSTRUCTIONAL SEQUENCE

5E Model Stages	Curriculum Materials: Specifications	Instructional Strategies: Essentials
Engage	The lesson should focus students' interest and thinking on the learning task. Curriculum materials should (1) activate current knowledge and make connections between past and present experiences, (2) anticipate activities of future lessons, and (3) physically and mentally engage students in the concepts, practices, and applications of the unit.	The teacher assesses learners' current knowledge and facilitates their interest and attention in new concepts and practices by posing questions, presenting discrepant events, showing a video, or giving a demonstration.
Explore	Instructional materials include activities that help students use current knowledge to generate ideas, explore questions and problems, consider possibilities, design investigations, obtain information, conduct web searches, and engage in discourse about their ideas. The lessons should establish a common base of experiences that students use to begin developing scientific and engineering practices, crosscutting concepts, and disciplinary core ideas.	The teacher encourages the examination of current concepts and exploration of practices as students encounter scientific questions and engineering problems. Instruction centers on using practices to challenge current ideas and abilities and begin formulating new concepts, abilities, and behaviors.
Explain	Instructional materials provide clear and succinct explanations for science concepts and engineering designs. Materials provide opportunities for group work where students explain their ideas to peers, review current explanations, read, listen to videos, search the web, and listen to the teacher.	Teachers directly explain concepts and practices and guide learners toward in-depth understanding. Instruction includes asking for clarification, providing definitions, and using students' current explanations as the basis for more accurate scientific explanations and definitions.
Elaborate	Lessons in this phase have students apply the concepts and practices to new situations. Instructional materials require the transfer of prior learning within reasonable range for students.	Teachers encourage the use of formal labels, definitions, and explanations and provide these if they are not expressed. Instruction has students use evidence for explanations and requires use of logic in formulation of arguments.
Evaluate	Lessons in this phase use the performance expectations as the basis for assessments of student learning.	Teachers may observe students and assess their understanding of concepts and practices and determine the degree to which they met performance expectations.

TABLE 10.8. A FRAMEWORK FOR INTEGRATING THREE DIMENSIONS OF *NGSS* USING THE 5E INSTRUCTIONAL MODEL

5E Model Stages	Teacher and Student Actions	Scientific and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engage	What Teacher Does			
	What Students Do			
Explore	What Teacher Does			
	What Students Do			
Explain	What Teacher Does			
	What Students Do			

Table 10.8 (*continued*)

5E Model Stages	Teacher and Student Actions	Scientific and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Elaborate	What Teacher Does			
	What Students Do			
Evaluate	What Teacher Does			
	What Students Do			

TABLE 10.9. A PLAN TO ADAPT INSTRUCTIONAL MATERIALS

Timeline	Summer	Fall	Winter	Spring	Comments
Year 1					
Year 2					
Year 3					
Year 4					

CONCLUSION

In a very real sense, this is a conclusion for Chapters 7 through 10. These chapters present the difficult but practical elements in a process of adapting current instructional materials to align with the *NGSS*. Professional development based on the adapted instructional unit also is recommended.

Professionals may use the activities, frameworks, and analysis as presented in the chapters, or they may select those activities that are most appropriate for their state, district, or school.

Now the challenge of beginning the reform of curriculum and instruction moves from this book to venues in states, regions, districts, and schools.

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CHAPTER 11

NGSS Frequently Stated Concerns: The *Yes*, *Buts*

After introductory presentations, individuals often express concerns about the *Next Generation Science Standards* (*NGSS*). Those concerns often begin with an acknowledgment of the idea of science education standards and the importance of *NGSS*, followed by a reason to doubt the efficacy of *NGSS* due to a particular factor. In short, the concerns take the form of *Yes, but*.

In this chapter, I address some of the *Yes, but* concerns. Some of the referents for the concerns lie beyond the *NGSS* and are the result of other variables, such as national politics, state budgets, or local priorities. With these acknowledged, the chapter provides clear and honest responses to the *Yes, but* concerns, especially to those that are frequently expressed.

YES, BUT ASSESSMENTS WILL HAVE TO CHANGE.

Whether assessments change will be up to states, school districts, and science teachers. Use of performance expectations in *NGSS* implies changes for assessments, so the intention is for assessments to align with the standards. The reality is that changes in assessments will not be immediate, especially at the state level. Furthermore, it will take at least three years to transition curriculum and instruction to the new assessments. So it will be some time before curriculum, instruction, and assessments change. If curriculum and instruction are changed with a careful eye on *NGSS* and the aim of advancing effective science curricula and instructional practices, it is unlikely that assessment scores will suffer, but if the science education community waits until assessments are in place and then initiates a reform of curriculum and instruction, it is virtually guaranteed there will be three to five years of poor assessment scores.

School districts and science teachers can begin using selected performance expectations to design formative assessments for local use, so assessments for formative purposes will certainly change. At some point, issues about assessment must shift to concerns about what is best for students and not just getting higher test scores. This book has provided examples of assessments based on *NGSS*; see, for example, Appendixes A and B and the *evaluate* sections in Chapters 5–7.

YES, BUT WE ALREADY HAVE *COMMON CORE STATE STANDARDS*.

The *NGSS* should be viewed as a complement to the *Common Core State Standards*. Connections to the *Common Core State Standards* for English language arts and mathematics are made for each standard. I would note the standards on reading nonfiction such as science narratives and the practices for science and engineering in *NGSS* illustrate the differences and complementarity between the two sets of standards. The *NGSS* are national and common to many states but are not common core. In the *NGSS*, emphasis is on science and engineering as opposed to literacy and mathematics, as in the *Common Core State Standards*.

For elementary teachers especially, the alignment of the *NGSS* and *Common Core State Standards* makes life easier. Sure, the writers of these documents have made translation difficult by using terms such as *cluster*, *boxed-sub-heading*, and *performance expectation*, rather than using similar vocabulary, but the foundational premises of these two documents, as well as the *Common Career Technical Core*, all change teachers and students in the same way. If you are already effectively implementing the *Common Core*, you likely have taken many of the first steps toward implementing the *NGSS*.

YES, BUT I'M ALREADY DOING THAT.

Really? I would suggest that there is no such thing as a perfectly aligned curriculum, so teachers have to refine, improve, and adapt materials as changes in science, society, and students require. It may be the case that some individuals have already implemented the *NGSS* innovations. This response often refers to a single dimension of the three described in *NGSS*—for example, crosscutting concepts. In other cases, there is an assumption that science and engineering practices are the same as scientific inquiry. In general, I doubt the *NGSS* are already implemented, so I question the response.

I do acknowledge the concern and recommend attempting to identify some current classroom practices that align with those described in the *NGSS*. Current activities and practices provide a place to further the vision of the NRC *Framework* and policies of *NGSS*.

YES, BUT THE OBSTACLES ARE TOO BIG AND TOO MANY.

The most significant obstacles that have to be overcome exist beyond the *NGSS*. Now that the standards are published and adopted by states, it will be up to those states and local jurisdictions to implement policies, programs, and practices, all designed to help students achieve the learning outcomes described in the standards.

One major obstacle is the current budget situation in many states. Adoption of the *NGSS* implies changes in curriculum, instruction, assessment, and the complementary professional development for teachers. The truth is, the reform of science education is expensive.

There is a compelling need for examples of instructional materials. Such materials need not be full courses of study; they may be shorter units demonstrating the integration of science and engineering practices, crosscutting concepts, and disciplinary core ideas. The units should include assessments. Finally, the units could be used as the basis for professional development.

YES, BUT MY STATE IS NOT ONE OF THE 26 LEAD STATES, AND WE ALREADY HAVE STANDARDS.

Although the 26 lead states have a commitment to seriously consider adopting *NGSS* (and some already have), it is clear that many of the remaining 24 states have monitored development of the *NGSS*, and a number of them may even adopt *NGSS* before some lead states. For example, in spring 2013, 46 state teams attended a Building Capacity for State Science Education (BCSSE) meeting that was facilitated by the Council of State Science Supervisors (CSSS). As the title indicates, the meeting centered on those teams developing the capacity to implement *NGSS* in their respective states. The fact that some non-lead states are anticipating *NGSS* and planning for their implementation at some level suggests that state standards will change.

History provides a perspective that lends support to my answer. In the 1990s, the *National Science Education Standards* (NRC 1996) influenced all states' standards, and this was despite the fact that we paid very little attention to states' priorities.

YES, BUT *NGSS* IS PROBABLY JUST ANOTHER EDUCATION FAD.

The insight that education has numerous and varied fads is accurate, unfortunately. However, from time to time, there are initiatives that far exceed the brief popularity of a fad. Although I have stated it elsewhere, I will state again—the power of standards resides in the fact that they influence changes in key components of the education system. Most education fads do not fit this criterion.

Release of new standards for states (i.e., *NGSS*) is more than a passing initiative. During the past several years, the widespread involvement of national organizations, state teams, and numerous individual reviewers has developed both awareness and support for *NGSS*.

The first generation of science standards was released in 1996. They have influenced science education since then. Having standards for science education is not another fad. One can expect *NGSS* to have at least some influence for a decade or more.

YES, BUT WHAT ABOUT STEM EDUCATION?

STEM is a popular slogan in American education. The acronym refers to science, technology, engineering and mathematics and is used in multiple contexts with varied meanings. Some have suggested the need for a federal definition of STEM. I doubt the federal government could or should define STEM. Indeed, many would not accept a federal definition of STEM simply because it was a federal definition. In *The Case for STEM Education: Challenges and Opportunities* (Bybee 2013), I suggested that it may be much more productive to identify STEM-related goals and identify connections between those goals and *NGSS*. That said, I present the following goals for STEM education:

1. Develop a STEM-literate citizenry.
2. Ensure a deep technical workforce with 21st-century needs.
3. Contribute to a pipeline of individuals in advanced research-and-development STEM careers.

STEM education should contribute to an individual's

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

To accomplish these goals, key aspects of *NGSS* and STEM will need to be combined in state and local policies, school curriculum programs, and classroom practices in ways that are coherent and focused on achieving the vision expressed in both *NGSS* and STEM.

YES, BUT WHAT ABOUT THE REAUTHORIZATION OF ESEA/NO CHILD LEFT BEHIND?

The impact the *NGSS* will have on the reauthorization of ESEA (aka No Child Left Behind) is unclear. *NGSS* could have a significant impact if the central features of ESEA continue to be assessment and adequate yearly progress. Some have advocated "Making Science Count" through assessments. The emphasis on assessments in ESEA/NCLB has resulted in increased attention to English language arts and mathematics, often at the expense of science and other subjects. So, advocating for assessment equality is one way to get more time for science in school programs, but states and districts should be prepared for budgetary consequences and other unanticipated consequences.

The role assessments play in ESEA is, at best, mixed. As mentioned, the increased emphasis on some disciplines at the expense of others is one outcome. Most important, time, attention, and resources have gone to attaining higher scores on assessments with little attention to improving teaching practice science programs or the assessment themselves. "Teaching to the test" and the orientation of NCLB (i.e., negative consequences for lack of adequate progress) have left many—including me—critical of this approach to educational improvement.

YES, BUT THE INCLUSION OF SCIENCE AND ENGINEERING PRACTICES IS JUST TOO MUCH.

This concern often is one of time as a constraint to the teaching of science. The basis for the concern rests on the premise that the primary aim of science education is to deliver information to students and engaging in the practices takes time from covering all of the content. It is time the science education community faced the reality that we will never teach all the information that is available and giving students experiences with the practices will help them with the ability to think and acquire information as needed. These are life skills important for citizenship. Because science and engineering practices are basic to science education and the change from inquiry to practices is central, this innovation for the new standards will likely be one of the most significant challenges for the successful implementation of science education standards.

The relationship between science and engineering practices is one of complementarity. Given the inclusion of engineering in the science standards and an understanding of the difference in aims, the practices complement one another and should be mutually reinforcing in curricula and instruction.

The shift to practices emerges from research on how students learn and advances our understanding of how science progresses. The new emphasis on practices includes scientific inquiry and goes beyond the descriptions of abilities and understandings of inquiry in NSES.

Indeed, the inclusion of science and engineering practices may result in greater learning and efficiencies for the classroom teacher. The new emphasis on practices reinforces the need for school science programs to actively involve students through investigations and, in the 21st century, digitally based programs and activities. Hands-on and laboratory work will contribute to the realization of practices in science classrooms. There is a reasonable assumption that the abilities and understandings of science and engineering practices will progressively get deeper and broader across the K–12 continuum.

Science and engineering practices should be thought of as both learning outcomes and instructional strategies. They represent both educational ends and instructional means. First, students should develop the abilities described in the practices, and they should understand how science knowledge and engineering products develop as a result of the practices.

Second, as instructional strategies, the practices provide a means to certain skills and cognitive abilities and other valued outcomes, such as students' understanding of the core ideas and crosscutting concepts expressed in the framework. In brief, the practices represent one aspect of what students are to know, what they should be able to do, and how they should be taught. Granted, this is a large order, and a concern about time is real, but from the perspective of K–12, teachers will have 13 years to facilitate students' attaining the goals.

YES, BUT THERE IS A REPORT CRITICAL OF *NGSS*.

It is indeed true that there is a report critical of *NGSS.* In June 2013, the Thomas B. Fordham Institute released an evaluation of the *NGSS*, giving it a grade of C. The evaluation included an analysis of the content, rigor, and clarity of *NGSS* and identified shortcomings such as

- inadequate prerequisite content in lower grades for high school physics and chemistry,
- failure to include math content critical to science learning,
- inclusion of assessment boundaries that likely will limit curriculum and instruction,
- failure to achieve a balance of integrating science practices with necessary content, and
- assumption that students in upper grades have mastered essential prerequisites in lower grades when the content is included in earlier grades.

It is appropriate to acknowledge some of the criticisms in the report. It may be the case that some prerequisites may be inadequate or that more math could have been included, for example. But criticism based on what was *not* included in standards can be stated for *any* set of standards. This criticism is an especially easy one to make when the teams developing the *NGSS* were consistently under pressure to reduce the amount of content and practices.

I think there is a second important point to make about the Fordham report. The basis for the evaluation was largely based on Fordham's comparison to states' standards for science education. I would note that one intention of the *NGSS* is to improve states' standards, which means changing those standards. In fact, the leadership for *NGSS* directly involved 26 states and responded to public reviews from other states. In short, one may have a critical review based on the status quo. The fact that the Fordham report finds fault with the *NGSS* should not be a surprise to anyone. What should be recognized is the overwhelming support from a majority of states and early adoption of *NGSS* by several states.

I will conclude by noting the contrast between the acceptance and support of *NGSS* by prominent science teacher organizations, state leaders, and many in business and industry and the critical review of nine individuals. While it is important to acknowledge the criticism and attend to appropriate faults in the *NGSS* as possible, it would be inappropriate to reject the *NGSS* based on one (or even two) initial reviews. The weight of the support clearly supports adopting the *NGSS* at the state level and, by implication, reforming science curricula, instruction, and assessment.

Conclusion

Science teachers undoubtedly have concerns about *NGSS*; I would be amazed if they did not. There is, however, an important distinction between concerns about and resistance to an innovation such as *NGSS*. I assume that most *Yes, but*s are expressions of concern and deserve a response. I have tried to address science teachers' concerns in this chapter.

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CHAPTER 12
Conclusion

A Framework for K–12 Science Education and the *Next Generation Science Standards* (*NGSS*) present a comprehensive and coordinated set of policies designed to improve science education. In this case, *improve* means bringing about higher levels of achievement for all learners. But between the *Framework* and *NGSS* and the goal of higher levels of achievement exists the gap of curriculum and instruction, and this gap is significant. What is not in this gap but is indispensable in achieving the goal are school science programs and materials for classroom instruction. Filling in the gap is what this book addresses.

The *NGSS* are based on *A Framework for K–12 Science Education* (NRC 2012). The *NGSS* were developed by a team of scientists, engineers, science teachers, informal educators, and science educators who had the difficult task of identifying the most important and fundamental knowledge and abilities that characterize science and engineering. That task was not easy. The standards simply could not include all the topics, skills, and ideas that a learned group could identify. Rather, the challenge was to focus on major concepts that form a core of physical, life, and Earth sciences. In addition, the content had to incorporate the ways of thinking, working, and investigating the natural world—science and engineering practices and concepts that unified the science.

Taken as a whole, the *NGSS* provide a conceptual framework of knowledge and skills that learners need to continue their study of science and meet their obligations as citizens. The standards address fundamental goals of education:

- Students should know what is central to science—standards on physical, life, and Earth and space sciences and crosscutting concepts.
- Students should develop cognitive abilities within the study of science—standards on science and engineering practices.
- Students should be prepared for responsible citizenship and able to apply knowledge and practices to a variety of personal and social problems—standards on engineering and the nature of science.

The *NGSS* reflect a broad consensus overlapping science research and science education communities. During the development process, feedback and support were continually sought from professionals on state leadership teams, national organizations, and the general public. The process was as thorough and comprehensive as time, budget, and personnel would permit.

The *NGSS* were crafted to be developmentally appropriate. By designing standards for grade levels K–5, 6–8, and 9–12, outcomes were identified that would be achievable regardless of students' perceived abilities.

Finally, the *NGSS* leave ample flexibility to accommodate the range of differences among states, communities, and schools. The tradition of local control and the requirements of student interests and abilities need not be sacrificed as the *NGSS* are implemented in the school science programs.

Despite the positive qualities, there remain some limitations. Standards are not a curriculum and do not engage in classroom instruction, meaning they don't teach students—teachers do. Will widespread dissemination of national standards provide adequate guidance for the implied transformation of curriculum materials and strategies for classroom instruction? This certainly was the intention. However, science educators and science teachers must understand the assumptions on which the standards were developed and consequently not assume that dissemination of the standards alone will result in the curricular changes. By design, standards do not provide complete curriculum programs or lessons for classroom instruction. Professionals with technical expertise to read, interpret, and use all dimensions of the *NGSS* will have to translate the policies into school science programs and classroom practices.

Common sense and education research support the conclusion that the science education community needs to do more than adopt standards to initiate and sustain the kind of changes outlined in both the *Framework* and *NGSS.* There are several reasons for this conclusion. First, the standards documents present practitioners with a formidable amount of information. Although the standards are well thought out, provide clear and accurate descriptions of performance expectations, and clarify the foundations of science and engineering practices and core and crosscutting concepts, they do not lend themselves to direct and easy use as school science curricula, professional development experiences, assessments programs, or the teaching of science in grades K–12. The standards look different than the prior generation and will alter the system. They must be translated into the materials, activities, and products that compose these programs and classroom practices.

Second, for the most part, the standards do not provide clear descriptions of processes for translating the *NGSS* into programs and practices. This observation should not be surprising because describing the process of implementing the standards was not the purpose of the document. Rather, the *NGSS* simply describe what students should know and be able to do. They do not describe the processes of programmatic development and implementation in classrooms.

Third, the changes implied by the *NGSS* present a complex array of interdependent issues involving content, teaching, assessment, professional development, school science programs, and systemic reform. Individuals and groups do not commonly review standards based on the array of interdependent factors; rather, they center on the single factor most closely aligned with that individual's or group's professional interest and, based on the review, infer what the standards may mean. Although examining and understanding the *NGSS* as an integrated set of policies is a professional obligation, this assumption is neither intuitively obvious nor commonly practiced.

Practitioners who have to interpret and translate the *NGSS* are often bound by their own views of science education programs and classroom practices. Historically, science teachers have found creative ways to help students memorize facts for the test. Teachers have done well using innovative techniques that attained short-term positive results on assessments. The teachers that these perceptions exemplify may be doing well, but it is the old model, not that of the new generation. These traditional views may contrast with the spirit of the *NGSS* and often are sustained by many commercial publishers, school boards, administrators, and communities. These views have to be challenged and shown to be inadequate for the current situation, and new ideas—school curricula and instructional practices—that are meaningful, feasible, and usable have to be developed.

The experience of developing the *NGSS* required two paradoxical assumptions—first, that the standards be clear and usable to students, teachers, curriculum developers, assessment specialists, and others who would understand what the standards require; and second, that the standards do not proscribe a national curriculum. At most, the *NGSS* provide performance expectations and implied examples of curriculum and instruction, but the developers had to stop short of recommendations that would be interpreted as a national curriculum. This was done with the assumption that enlightened professionals would assume the responsibility for appropriately and adequately translating the standards. What I have stated here is primarily the paradox of developing national standards in a country that maintains local control over educational programs.

Since the 1980s, there has been a national conversation about standards, beginning with *A Nation at Risk* (U.S. Dept. of Education 1983) and continuing with *Science for All Americans* (Rutherford and Ahlgren 1989), *Benchmarks for Science Literacy* (AAAS 1993), *National Science Education Standards* (NRC 1996), and, most recently, *Common Core State Standards* (NGAC and CCSSO 2010). The *NGSS* (Achieve 2013) will continue that conversation. Essentially, the conversation centers on questions about the knowledge, values, skills, and sensibilities that we want future citizens to have in common (Cremin 1976). The conversations about standards heard in national forums, state departments, and local districts are sometimes difficult, or even distressing, but they are important and fundamental to our democracy.

While that national conversation continues, standards also have been the basis for changes in national, state, and local policies; elementary, middle, and high school programs; and curriculum, instruction, and assessment practices in classrooms. So, I am confident in responding to a question about the past influence of national standards by stating that they have demonstrated one very important characteristic: It is abundantly clear that national standards have changed fundamental components of science education at a scale that makes a difference. Some would certainly question whether the changes have been good or bad. I argue that on balance, national standards have had a positive influence on the science education system. Many of the negative effects attributed to standards are actually due to large-scale assessments and the accountability models that drive those assessments. This said, the influence of national standards has often been a weak force on the education system. That is the disappointing news. The good news is that the influence of national standards has been continuous and generally in the direction of more coherent, focused, and rigorous state policies, school programs, and classroom practices. After release of the standards in 1996, the National Research Council (NRC) undertook the task of developing a framework for research in mathematics, science, and technology education. The report has been used to frame questions and guide investigations of the influence of standards (NRC 2002). There is some evidence supporting the generally positive influence of national standards (NRC 2003; Sunal and Wright 2006).

In the early years of the 21st century, there were new calls for national standards from several major urban school districts, the Council of Great City Schools (CGCS), Council of Chief State School Officers (CCSSO), National Governors Association (NGA), the National Science Board (NSB), and some members of Congress. These discussions were simultaneously encouraging and discouraging. They continued the national conversation about what our society needs from the science education community: What is the role of standards? What are the required fundamental changes within the science education system? These discussions present the encouraging side of calls for national standards. The *NGSS* build on and complement these calls for standards-based reform.

As to the discouraging side of the discussion, from its enactment in January 2002, the No Child Left Behind Act (NCLB) has placed time and attention on literacy and mathematics and used assessment results as a means of determining adequate yearly progress for schools attaining (or not attaining) required outcomes. In 2007–2008, student achievement in science was included as an outcome. While the title "No Child Left Behind" represents a significant and explicit statement of equity and civil rights, unfortunately, the mechanisms for implementation were generally unequal. In the Sputnik era, we learned that "teacher-proof" science curricula were not effective. Now, in the NCLB era, many educators are realizing that "school punishment" likewise is not an effective strategy to improve student achievement.

One major issue in the use of standards as a stimulus for reform has been a lack of high-quality instructional materials developed to complement the standards. We have the policies and assessments but lack curriculum materials that will facilitate effective science teaching. The omission of well-designed instructional materials will have long-term detrimental consequences for science education. This was true in the 1990s and will be true for the second decade of the 21st century.

The *NGSS* provide a constructive response to several national issues. The continued interest in the public's attention to the low ranking of students in the United States on international assessments presents one issue for which the influence of the *NGSS* will be considered. One of the insights from higher-achieving countries is the coherence of their school science curricula, teacher development, assessments, and classroom instruction. Continued attention to the *NGSS* will serve to increase coherence among the central components of science education. This view builds on the long-term positive benefit of the standards. Second, the *NGSS* emphasize the integration of science concepts and practices; this approach holds the possibility of addressing several of the important outcomes that are consistent with recommendations from business and industry—understanding systems, solving complex problems, developing critical thinking, and using evidence as the basis for decisions. Finally, there are emerging concerns about America's economic competitiveness and the need to prepare a 21st-century workforce. Here, too, national standards could provide a valuable influence as we consider the needs and appropriate responses for science education.

Two recent statements underscore the need for national standards. On May 4, 2007, *Science* had a brief article on the National Science Board's report on STEM education. With the headline "Report Urges More Coordination to Improve Science and Math," the report suggested the need for national standards (NSB 2007). And on June 8, 2007, the *New York Times* carried an article on the release of a U.S. Department of Education report that measured the extent of differences among states' academic standards. The headline, "States Found to Vary Widely on Education," and the article's first sentence tells the story: "Academic standards vary so drastically from state to state that a fourth grader judged proficient in reading in Mississippi or Tennessee would fall short of that mark in Massachusetts and South Carolina. …" (*New York Times* 2007; complete report can be found at NCES 2007). For me, both of these articles make the case for the *NGSS* and the need for well-designed instructional materials and assessments.

The *NGSS* raise the academic bar for states and still leave them with the freedom to adopt or adapt materials and provide professional development to attain higher levels of achievement—for all students. The *NGSS* present an opportunity for states, districts, teachers, and communities to move our nation forward in science education. In this book, I have tried to set the stage by acknowledging the context within which the *NGSS* are proposed and provide concrete steps for beginning to move forward. After all, science education standards don't teach students—science teachers do. The *NGSS* provide direction toward the effective design of curriculum and best classroom instruction.

The *NGSS* provide a central focus for conversations and debates about their role in student achievement. Now the nation's efforts must center on the translation of

Standards into high-quality school programs, effective classroom instruction, and appropriate assessments.

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APPENDIX A

Grade 5 *NGSS* Unit, "Is It a New Substance?"

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ALIGNMENT

PE	5-PS1-4: Conduct an investigation to determine whether the mixing of two or more substances results in new substances.
DCI	PS1.B: Chemical Reactions: When two or more different substances are mixed, a new substance with different properties may be formed.
SEP	Planning and Carrying Out Investigations: Conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered.
CCC	Cause and Effect: Cause and effect relationships are routinely identified, tested, and used to explain change.
CCSS Connections	W.5.7: Conduct short research projects that use several sources to build knowledge through investigation of different aspects of a topic. W.5.8: Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources.

IS IT A NEW SUBSTANCE?

Students conduct an investigation to determine if two substances combine to form a new substance. The students are told to mix Substance W with a solution of Substance X dissolved in water. The students need to complete the investigation to gather evidence that supports the claim that a new substance is formed.

Claim: Substance W can combine with Substance X and form a new substance.

Student 1 plans to use a balance to measure the mass of the substances at the beginning and at the end of the investigation.

Student 2 plans to use her sight to observe whether the substances change color in the investigation.

ITEM 1—MC

Which student's investigation would **most likely** support the claim that a new substance is formed?

A. Student 1's, because mass can be more accurately measured than color

B. Student 1's, because the mass of a new substance would be equal to that of the previous substance

C. Student 2's, because a color change often indicates a new substance

D. Student 2's, because color is the most difficult characteristic of a substance to change

KEY: C

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ITEM 2—MC

To compare Student 1's and Student 2's investigations, what variable is **most important** to keep the same during the two investigations?

A. the amount of time

B. the amount of Substance W

C. the equipment used to mix the two substances

D. the temperature of the water used to dissolve Substance X

KEY: B

ITEM 3—CR

Choose one of the students' investigations.
Describe two ways that investigation can be changed to gather more scientific evidence to support the claim. Be sure to explain your reasoning.

SCORING

Full credit

The response describes two ways either investigation can be changed and explains how each method supports the claim.

- perform more trials—this produces repeated data to confirm the results
- vary the amount of Substance W—this helps make sure that a change is not due to uncontrolled variables
- use a zero amount of Substance W (include a negative control)—this helps make sure that Substance X isn't combining with something else
- test another substance that is known to combine with Substance W (include a positive control)—this helps make sure that Substance W can combine as expected (i.e., has not lost reactivity)
- evaluate more characteristics of the substance formed (such as dissolving/not dissolving in water, melting point, etc.) instead of relying on color change or mass change—this supports that a new substance is formed if these identifying properties have changed

Note: Measuring mass can be used as a valid response if the response shows how the mass of Substance W and Substance X change in proportion to the new substance(s). (Only measuring the total mass of the system, as Student 1 did, is not acceptable for credit.)

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Partial credit
The response describes one way either investigation can be changed and explains how the method supports the claim, or describes two ways the investigation can be changed but does not include an explanation. Possible responses include any of the changes and/or explanations above.

No credit

- The response may describe changes to the investigation in general, but the response lacks the specifics connected to the formation of new substances.
- Off task or unrelated response.
- Blank/missing response.

APPENDIX B

Middle School *NGSS* Unit, "Water and Hydrogen Peroxide"

ALIGNMENT

PE	MS-PS1-1: Develop models to describe the atomic composition of simple molecules and extended structures. [Clarification Statement: Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.] [Assessment Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete depiction of all individual atoms in a complex molecule or extended structure.] MS-PS1-5: Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved. [Clarification Statement: Emphasis is on law of conservation of matter and on physical models or drawings, including digital forms, that represent atoms.] [Assessment Boundary: Assessment does not include the use of atomic masses, balancing symbolic equations, or intermolecular forces.]
DCI	PS1.A: Structure and Properties of Matter: Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. PS1.B: Chemical Reactions: The total number of each type of atom is conserved, and thus the mass does not change.
SEP	Developing and Using Models: Develop a model to predict and/or describe phenomena. Developing and Using Models: Develop a model to describe unobservable mechanisms.
CCC	Scale, Proportion, and Quantity: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. Energy and Matter: Matter is conserved because atoms are conserved in physical and chemical processes.
CCSS Connections	RST.6-8.7: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). MP.2: Reason abstractly and quantitatively.

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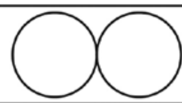
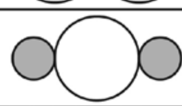
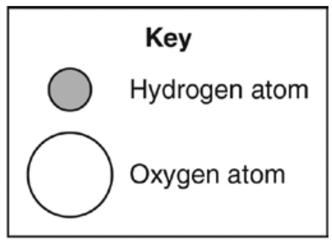
WATER AND HYDROGEN PEROXIDE

Water molecules and hydrogen peroxide molecules each consist of only hydrogen and oxygen atoms. A water molecule consists of two hydrogen atoms and one oxygen atom. A hydrogen peroxide molecule consists of two hydrogen atoms and two oxygen atoms.

The table below shows molecular models for hydrogen, oxygen, and water.

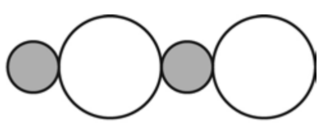
Substance	Molecular Model
hydrogen	
oxygen	
water	

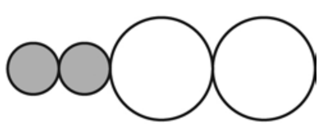


When an electric current passes through water, the water molecules decompose (break down) into hydrogen molecules and oxygen molecules.

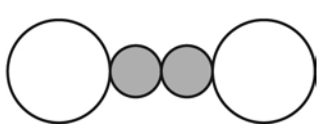
ITEM 1—MC

Which molecular model represents hydrogen peroxide?

A. 

B. 

C. 

D. 

KEY: C

ITEM 2—MC
Based on the molecular models in the table, how are hydrogen molecules and oxygen molecules alike?

A. Each molecule is made up of two atoms.
B. Both molecules are about the same size.
C. Both molecules can decompose to water molecules.
D. Each molecule consists of more than one type of atom.

KEY: A

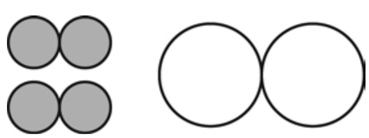
ITEM 3—CR
An electric current causes two molecules of water to decompose.

Draw all the molecules that result from the decomposition and explain how your drawing shows that mass is conserved.

SCORING

Full credit

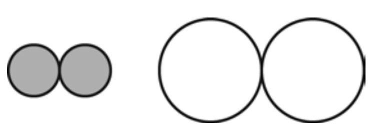
The response includes a drawing of the molecules that result from the decomposition and an explanation of how the drawing shows that mass is conserved.



The drawing shows that mass is conserved because the drawing contains the same number of each type of atom as the original two water molecules (four hydrogen atoms and two oxygen atoms).

Partial credit

The response contains a drawing of the molecules that result from the decomposition, or an explanation of how mass is conserved, or partial answers to both parts.



The same atoms are in this drawing and the original two water molecules.

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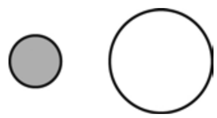
No credit

- Incorrect answers may include:
  - a diagram of one hydrogen atom and one oxygen atom:



  - The hydrogen and oxygen molecules are saved to be used another day.
- Off task or unrelated response.
- Blank/missing response.

Source: "*NGSS* Unit: Water and Hydrogen Peroxide." Commissioned.

APPENDIX C

High School *NGSS* Unit, "The Haber–Bosch Process"

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ALIGNMENT

PE	HS-PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]
DCI	PS1.B: Chemical Reactions: In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. PS1.B: Chemical Reactions: Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. ETS1.C: Optimizing the Design Solution: Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed.
SEP	Constructing Explanations and Designing Solutions: Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
CCC	Stability and Change: Much of science deals with constructing explanations of how things change and how they remain stable.
CCSS Connections	WHST.9-12.7: Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. RI.11-12.7: Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a question or solve a problem. HSF-IF.B.4: For a function that models a relationship between two quantities, interpret key features of graphs and tables in terms of the quantities, and sketch graphs showing key features given a verbal description of the relationship. Key features include: intercepts; intervals where the function is increasing, decreasing, positive, or negative; relative maximums and minimums; symmetries; end behavior; and periodicity.

* This is an engineering PE.

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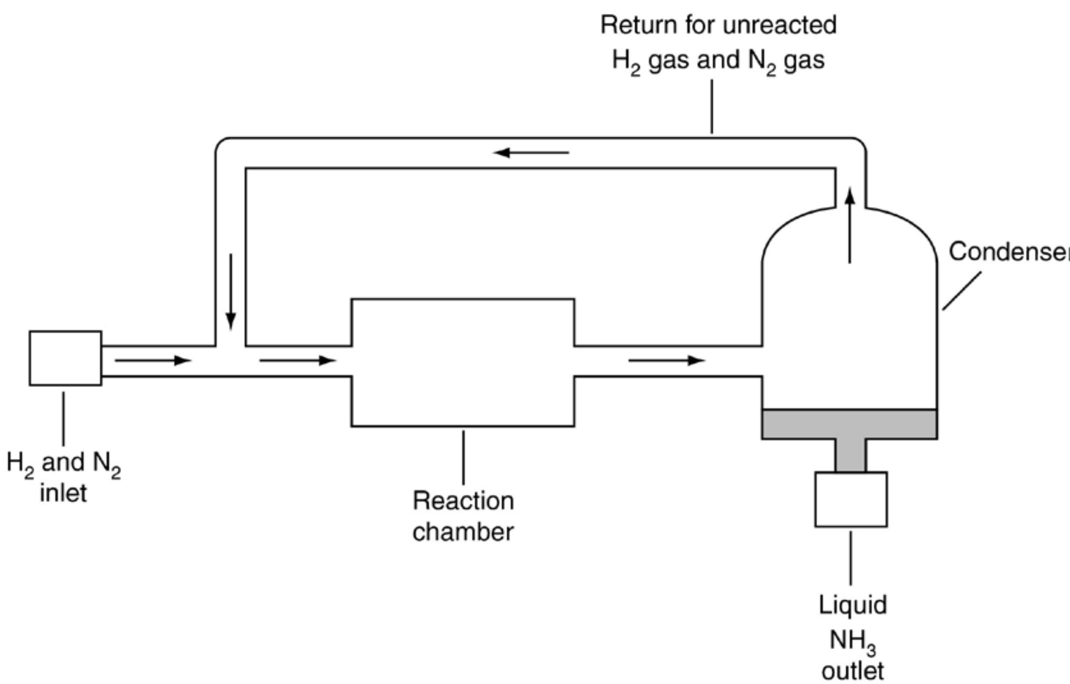
THE HABER-BOSCH PROCESS

The compound ammonia (NH_3) is used to manufacture many commercial fertilizers. Ammonia can be produced by reacting hydrogen gas (H_2) with nitrogen gas (N_2). The reaction is exothermic, releasing heat. If left undisturbed, the reaction system will reach equilibrium, as shown in the equation below.

$$3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g) + \text{heat}$$

A chemist named Fritz Haber developed a process to produce ammonia directly from hydrogen and nitrogen as shown in the equation. An engineer named Karl Bosch designed the equipment needed for the process, and today the Haber-Bosch process is the primary way that ammonia is produced on an industrial scale.

The diagram below shows a general design for industrial ammonia production using the Haber-Bosch process. Hydrogen gas and nitrogen gas enter a reaction chamber. Hydrogen gas, nitrogen gas, and the resulting ammonia gas then move into a condenser. The condenser contains a cooling unit at a temperature below the boiling point of ammonia but above the boiling points of hydrogen and oxygen. The resulting liquid ammonia is removed from the bottom of the condenser, while hydrogen gas and nitrogen gas return to the reaction chamber.



Chemists and engineers consider different factors when determining the reaction system conditions and equipment for the process. The chemists and engineers must balance scientific, engineering, and economic constraints to produce as much ammonia as possible (highest yield). Some of the factors that are considered are listed on the next page.

- temperature of the system
- pressure of the system
- use and type of catalyst
- concentrations of reactants
- materials used to build the equipment
- layout of the equipment
- operating costs

ITEM 1—MC

A group of chemists and engineers is evaluating a proposed change to the system: the condenser would be removed, and gases from the reaction chamber would instead be passed through a special liquid. The liquid would absorb ammonia gas and remove it from the system, while hydrogen and nitrogen gases would not be absorbed.

Which statement explains whether this design change is consistent with the goal of maintaining high ammonia yield?

A. This change is consistent with the goal, because the liquid is in the same state as the final ammonia product that is desired.

B. This change is consistent with the goal, because any removal of ammonia from the reaction system would increase the forward reaction rate to replace the ammonia molecules.

C. This change is not consistent with the goal, because the liquid would compete with any catalysts that were added in the reaction chamber.

D. This change is not consistent with the goal, because the reaction chamber would become filled with too much hydrogen gas and nitrogen gas as ammonia is absorbed.

KEY: B

ITEM 2—MC

Which statement identifies the temperature conditions that favor high ammonia yield according to chemical equilibrium principles, and also identifies a tradeoff in choosing the actual temperature for the system?

A. High temperature favors the equilibrium shift toward ammonia, but it would result in fuel costs that are higher than the profit earnings.

B. High temperature favors the equilibrium shift toward ammonia, but it would decrease the density of unreacted gases too much for them to return back to the reaction chamber without pumps.

C. Low temperature favors the equilibrium shift toward ammonia, but it would result in a reaction rate that is too slow to make enough ammonia in a reasonable time period.

D. Low temperature favors the equilibrium shift toward ammonia, but it would change the pressure of the system so much that the walls of the equipment would burst outward.

KEY: C

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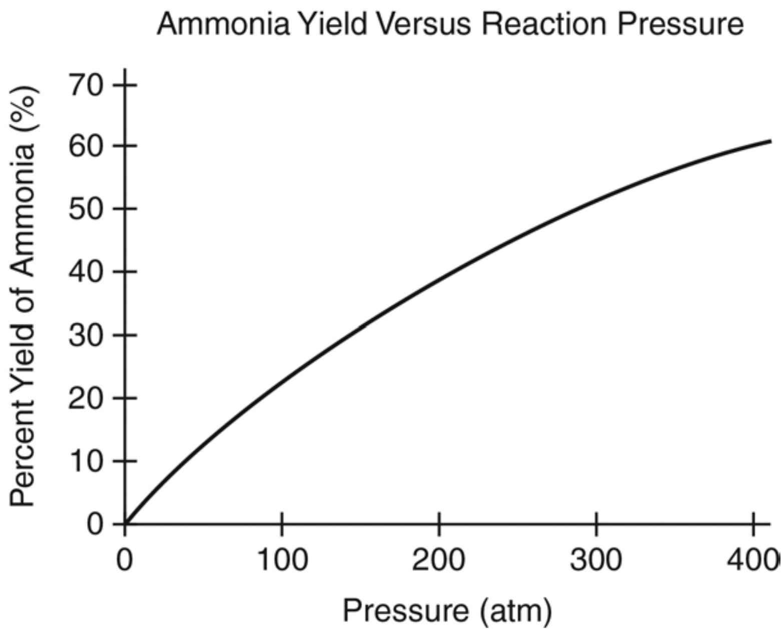
ITEM 3—CR

The graph below can be used to consider the pressure at which to operate the system for the Haber-Bosch process.



The system is not usually operated at the optimal pressure for maximum ammonia yield.

a. Identify the pressure conditions that favor maximum ammonia yield, and explain, according to chemical equilibrium principles, why that pressure favors maximum ammonia yield.

b. Discuss a constraint that causes chemical manufacturing companies to operate the system at a non-optimal pressure.

SCORING

Full credit

The response identifies and explains the pressure conditions that favor maximum ammonia yield, and discusses a constraint that causes companies to operate the system at a non-optimal pressure.

- High pressure conditions favor maximum ammonia yield, because to relieve the stress on the system, the equilibrium will shift to favor the reaction that produces fewer molecules, which is the forward reaction producing ammonia.

  One constraint on using high pressure is that special equipment is needed to withstand that pressure, and that equipment is expensive.

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- 400 atm of pressure favors maximum ammonia yield, because according to Le Chatelier's Principle, equilibrium will shift to reduce the high pressure by favoring production of 2 ammonia molecules rather than 4 hydrogen and nitrogen molecules.

  One constraint on using high pressure is that it is expensive to produce that pressure condition.

Partial credit

The response identifies and explains the pressure conditions that favor maximum ammonia yield, or discusses a constraint that causes companies to operate the system at a non-optimal pressure, or provides partial answers to one or both parts.

- High pressure favors maximum ammonia yield, because equilibrium will shift to the side of the equation with fewer molecules, which is the ammonia.
- High pressure favors maximum ammonia yield, but special equipment is needed to withstand that pressure.
- 300–400 atm of pressure favors ammonia production.
- The cost of producing the optimal pressure is a constraint.
- Having the right equipment to handle the optimal pressure is a constraint.

No credit

- Incorrect answers may include:
  - low pressure
  - specific pressure values less than 300–400 atm
  - Equilibrium shifts to favor the side of the equation with more molecules.
  - Equilibrium shifts because of Le Chatelier's Principle.
  - One constraint is that pressure this high cannot be produced.
- Off task or unrelated response.
- Blank/missing response.

Source: "*NGSS* Unit: The Haber-Bosch Process." Commissioned. ©2013 Measured Progress. All rights reserved.

APPENDIX D

Adapting a Unit of Study for Classroom Instruction

By Mark Salata, Eric Lam, and Rodger Bybee

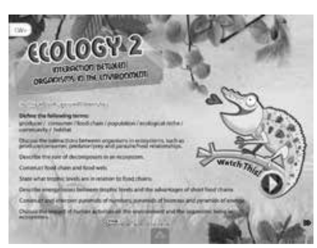
Early in 2013, we recognized a need for units of study that exemplified the essential features of the forthcoming *Next Generation Science Standards* (*NGSS*). We investigated the possibilities of revising a portion of a digital program for middle school. Shortly after the release of the *NGSS* in April 2013, we identified a unit of study with what we perceived as high potential for revision. We initiated work on adapting that unit of study. The box below presents information about the results of our collective efforts. The unit is available free of charge for your review and possible use. This unit represents an attempt to revise current materials based on the requirements of *NGSS*. We can tell you that the process was neither easy nor a perfect alignment. Following is a brief overview with background, a description of the process, and some pitfalls, precautions, and helpful recommendations.

The *NGSS* provide a challenge for science educators—a challenge that should be welcomed. With the *NGSS*, we have the collected input of many of the best science teachers, science educators, and scientists whose interests are in the improvement of student learning and classroom teaching. In terms of student learning, these standards are not statements of scientific facts; they are thoughtful performance expectations that support educators in providing rich and thoughtful learning experiences. With regard to teaching, the standards are written clearly and distill the complex domain of science into three key components: science and engineering practices, disciplinary core ideas, and crosscutting concepts.

To help you revise your lessons and units of study to produce the type of classroom instruction and student learning the authors of the *NGSS* intended, we present the following thoughts about our own experience adapting one of our successful interactive ScienceWerkz apps, "Ecology 2" (see below).

ScienceWerkz® is a line of apps designed as highly interactive eBooks that include video, animations, simulations, and other digital designs to provide an immersive experience for students—all off-line. The grade-level use of ScienceWerkz ranges from middle school through high school depending on the app's unit of study. Its reading level is approximately 8th to 9th grade.

The "Ecology 2" app addresses the interdependent relationships in ecosystems, focused on food chains, food webs, and the transfer of energy. A free trial copy of the NGSS-adapted version will be available for tablets. Check *www.werkzpublishing.com* for availability of this app and others.



We will review our understanding of the BSCS 5E Model briefly, then address how the 5E Model was used as a guide for the revision. Then we will review the *NGSS* structure and how it can be used to facilitate revision of lessons and units of study. Finally, we will summarize key points that we think will help educators revise their current materials to fit within the *NGSS* framework.

THE BSCS 5E INSTRUCTIONAL MODEL

For our revision, we used the BSCS 5E Instructional Model because, at their core, the ScienceWerkz apps already were framed within the model. Before explaining how the 5E Model was used to revise the "Ecology 2" app, here is a brief overview of the 5E Model.

The 5E Model uses what is known about good teaching practices and student learning. It consists of five phases known as *engage*, *explore*, *explain*, *elaborate*, and *evaluate*. In each phase, the teacher and student(s) take on particular roles within activities.

In the *engage* phase, the teacher provides an opportunity to initiate the students' learning with something to pique their curiosity, recall past experiences, or simply inquire about things related to the learning outcomes. The teacher uses this time to understand what the students already know and understand and identifies what is most relevant to the student as well. The students share their interest through questions, claims, and anything they can relate to that is part of the *engage* activity.

From the *engage* phase the teacher provides an opportunity to *explore*. In this phase, the students use their past knowledge, experience in the *engage* phase, and personal understanding to explore the topic under study. The teacher uses this time to assess students' current knowledge in the context of the exploration activity. Scientific terminology is not introduced, and students are encouraged to use their own words to describe what they do and understand. The *explore* experiences provide the teacher greater insights into student knowledge and understanding to address knowledge gaps as well as apply student knowledge to the rest of the phases. In this way, the unit of study is brought back to making it relevant and student centered.

The *explain* phase follows the exploration to consolidate student learning and provide scientific terminology to the students. Thus, students' experiences in the *engage* and *explore* phases will have labels and identifiers that scientists use to formally share and test ideas. This is the phase in which students explain their own understanding as well—an important opportunity for the teacher to continue probing the student mind and considering what context should be provided in the next phase for the greatest benefits for learning.

The *elaboration* phase is a similar context to the *explore* or a new context in which students apply what they have gained from the previous phases. Teachers encourage students to use the scientific terminology when working in this phase. The terminology is used for sake of precision and not merely to incorporate unusual words. Teachers assess students in this phase through active processes of questioning and critical discussion.

The *evaluate* phase completes the unit of study with student and teacher reflection on the development and growth of the learner as compared to where each was at the *engage* phase. Metacognition is encouraged and teachers evaluate not only the end of the 5E Model in terms of student learning but also the whole process of the 5E Model in light of the original learning goals.

USING THE BSCS 5E MODEL AS A GUIDE

Guiding the Context of Teaching and Learning

With the aforementioned in mind, we reviewed our app and considered how best to make the actions of the students and teacher more explicit in the Ecology 2 unit. We decided to include in the teacher's version an integrated teacher's guide that would not only include references to the specific parts addressed from the *NGSS* but also help teachers be reminded of the 5Es and the importance of staging certain actions.

For example, teachers may tend to front-load a unit of study by providing the students with new content and unfamiliar scientific terms. These terms may be familiar to the science teacher due to regular use, but for students they may be as odd as words from a foreign language. Without experiences to tie to the terms, the learner is forced into a mode of memorization devoid of the variety of learning modalities that can be tapped through personal experience.

This front-loading would be inconsistent with the structure of the 5E Model because both the *engage* and *explore* phases (the first two phases) are designed to allow students to tap current experience and knowledge and use their own words to describe phenomena. It is the third phase, *explain*, in which scientific terminology is brought to the forefront because students then have experiences (possibly both mental and physical) that have personal meaning. Thus, the scientific terminology has a context and makes sense.

So we included brief commentary in the teacher's guide to remind teachers how each page of the Ecology 2 unit fits within the 5E Model. These brief comments and the inclusion of what the roles are for the teacher and student(s) during each of the phases help create a clearer image of the implementation for the teacher.

We can take advantage of the interactive digital format of ScienceWerkz by having a simple button on each page that does not distract from the content. In a traditional hard copy, teachers might have an appendix, separate teacher's guide, or their own special version that shows a miniaturized student version with teacher notes on the sides. In ScienceWerkz, a teacher can quickly slide the guidance page over the Ecology 2 content, pulling the details of a footnote out, view the page, and slide it back. Because ScienceWerkz is not dependent on the internet after it has been downloaded, teachers can be assured that the core content and teacher's guide is always available.

Revising the Content of the Unit of Study

In addition to using the 5E Model to make the context of teaching and learning more explicit, we used the model to guide our revision of the content itself. We reviewed the content in the Ecology 2 unit and asked, "Is this really appropriate for the ______ phase in the 5E Model? Can it be moved somewhere else? Should it be dropped from the unit?" The answers to these questions helped us rearrange a few items, drop one or two items, and be reassured that the original approach with the 5E Model helped us stay a step or two ahead in this process as compared to traditional lessons.

We were also mindful of the fact that the 5E Model could be devised in such a way that certain phases are repeated using different content. For example, the full content of the Ecology 2 app was not structured as only the 5Es going from *engage* through to *evaluate*. In fact, in the end, we saw a natural structure that included two full cycles of the 5E Model: *engage* through *evaluate* for the first cycle, and then *engage* through *evaluate* for the second cycle.

NEXT GENERATION SCIENCE STANDARDS (NGSS)

When reviewing the *NGSS*, we were challenged with the new structure as compared with typical science standards that have been used in the past. These standards do not easily conform to the content-based structure with which we are so familiar. At first glance, this can be seen as a difficulty for revising a unit of study; however, it is a challenge well worth the effort because the *NGSS* not only take into account the content that a student is expected to learn but also provide a context for learning content. Additionally, the performance expectations (PE) are written in such a way as to enable an educator to think deeply about the goal of achieving scientific literacy for the 21st century.

NGSS *Design, Framework, and Revision*

For revising a unit of study, we first had to understand the structure of the *NGSS* and become familiar with its design and framework. The performance expectations (PEs) were used as the foundation to which we would constantly return, with the refrain, "Where in the lesson are we connecting to the performance expectation, and what is our evidence for this?" At first, the refrain was used as a global reminder that we had to connect both the practices and content of the unit of study to the PEs. As we developed the unit of study in greater detail in terms of what practices and content to include and what actions the students and teacher would take, we asked this question and pointed to specific instances where the PEs were met.

To help us be sure that specific content and context met the PEs, we used the three key components of the *NGSS* to revise the "Ecology 2" app or simply recognize that the original unit of study contained them. The three components supporting the PEs are the science and engineering practices, disciplinary core ideas, and crosscutting concepts. Each of these use labeling that helped us link back to the PEs. For example, the first crosscutting concept that we connected to in our Ecology 2 unit was patterns. The concept of patterns is described with the statement "Patterns can be used to identify cause and effect relationships. (MS-LS2-2)" The label "MS-LS2-2" is a direct reference to the PE, which states "Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems." In addition to the label, it was helpful to have the clarification statement that is shown below the MS-LS2-2 performance expectation. It is this flow of study of the *NGSS* that was required while revising the Ecology 2 unit.

Most important for connecting the PEs to the three components was becoming familiar with the aspects of science content, scientific practices, and scientific thinking with which the three components dealt. The most familiar of the three were the disciplinary core ideas. These will be familiar to educators because they most closely resemble the traditional science standards. Even with that comparison, however, the disciplinary core ideas do not provide specific facts, which are the basis of most current assessments. For example, one disciplinary core idea that we dealt with in this effort states, "Organisms, and populations of organisms, are dependent on their environmental interactions both with living things and with nonliving factors." These are rightly referred to as *ideas* and not *facts*. They are not facts to be memorized, but rather major ideas to be understood. The creator of the lesson or unit of study must convey these ideas through a rich learning experience, and that is the challenge for meeting the requirements of the disciplinary core ideas in particular, and the *NGSS* overall.

The other two components, the science and engineering practices and crosscutting concepts, are familiar to scientists and science educators as being important to understanding the nature of science and its applications. These also are organized with the same type of labels referring back to the performance expectations (PEs). With both of these, we would go back and forth with the original content and ask whether or not the individual parts of the science and engineering practices and crosscutting concepts were found in the instructional activities For example, we examined whether or not some of the content was truly having students "[d]evelop a model to describe phenomena (MS-LS2-3)" or providing them opportunities to "[a]nalyze and interpret data to provide evidence for phenomena (MS-LS2-1)"? If we thought that it did, then we would go back and re-read the related PEs to be more confident of the original content linking to it, or consider how it could be modified or replaced by more appropriate content.

NGSS *Terms and Phrases*

Finally, we created an approach to the content that allowed for greater alignment with the *NGSS*. For example, where we could, we replaced terms and phrases with the terms and phrases found within the *NGSS*. This was done for two reasons: (1) to help the teachers who use our "Ecology 2" app quickly recognize the alignment, and (2) to help us quickly recognize what needed to be revised from the original content and what could remain the same.

The terms *abiotic* and *biotic* were updated to be *nonliving* and *living*. The phrase "interdependent relationships in ecosystems" became common and helped us recognize whether content was addressing this or not. From the science and engineering practices, the "developing and using models" idea brought on a great discussion as to whether a few of our highly interactive pieces in the app were addressing the scientific concept of a model appropriately.

This altering of words may seem trivial, but within the words we use there is meaning. By aligning the words, we align the meaning and, in the end, the student understandings intended by the *NGSS*.

Conclusions

There are a few key points that we learned in this process. First and foremost, the *NGSS* are light years ahead of the former standards in promoting the kind of teaching and learning that we know is best based on educational research. The *NGSS* promote a depth of thinking and breadth of knowledge that are appropriate for the needs of a scientifically informed society. With this complexity, the authors of the *NGSS* do a wonderful job organizing the material to allow for educators to adapt current lessons and units of study.

To complete the adaptation with the intended objectives of the *NGSS* in mind, however, educators should have in-depth knowledge of the BSCS 5E Instructional Model (or a similar model that has a rigorous research basis) and the patience to familiarize themselves with the *NGSS* and *A Framework for K–12 Science Education* (NRC 2012). A strong instructional model can provide the structure for the teacher and student roles, while the *NGSS* provide the content in context with performance expectations.

We recommend that you take one lesson or unit of study and begin the process of adapting what you have. Take time to revisit the content and consider its structure with the question, "Where does this connect to the performance expectations, and what is my evidence?" Asking this question of yourself and of colleagues within a collaborative environment should help you break away from the less effective and more traditional modes of teaching and learning.

We hope that this brief overview of our efforts to revise our "Ecology 2" app will serve you well, and we look forward to your feedback upon its release to the public as an *NGSS*-adapted product. We welcome you to check in, try the app, and give us feedback on it and all of the other ScienceWerkz apps available on our website (*www.werkzpublishing.com*).

Mark Salata is the director of pedagogical design at Werkz Publishing. Eric Lam is the director of pedagogical design at Amdon Consulting. Rodger Bybee is the retired executive director of the Biological Sciences Curriculum Study (BSCS).

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

TRANSLATING *the* NGSS *for* CLASSROOM INSTRUCTION

» How will the *Next Generation Science Standards* (*NGSS*) affect science teaching?

» How do educators translate the standards to classroom practices?

» Are there instructional materials that align with the standards?

» How does teaching (in the elementary, middle, or high school grades) fit into the K–12 science curriculum?

» Will the national, state, and district assessments change?

With the release of the *NGSS*, you need a resource to help you answer pressing questions about how the standards fit with your curriculum, instruction, and assessments. Rodger W. Bybee's *Translating the* NGSS *for Classroom Instruction* provides essential guidance for everyone from teachers to school administrators to district and state science coordinators. As practical as it is timely, this book includes an introduction to the *NGSS*; examples of the standards translated to classroom instruction in elementary, middle, and high school; and assistance in adapting current units of instruction to align with the standards.

Bybee notes that the success of the new standards depends greatly on teachers' ability to give students opportunities to learn the science and engineering practices, crosscutting concepts, and disciplinary core ideas of the *NGSS*. Reading this book is an important first step toward addressing educators' questions and concerns about how to provide those opportunities and implement the standards.

Grades K–12

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