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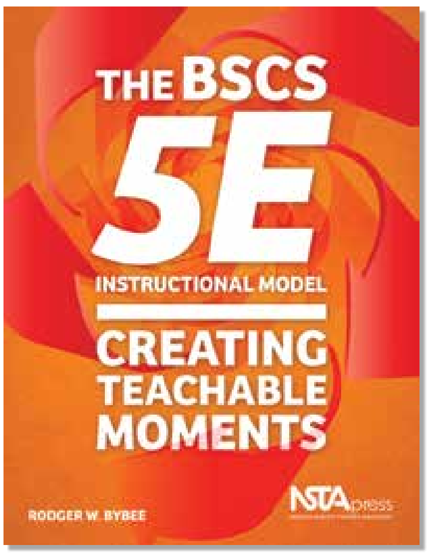

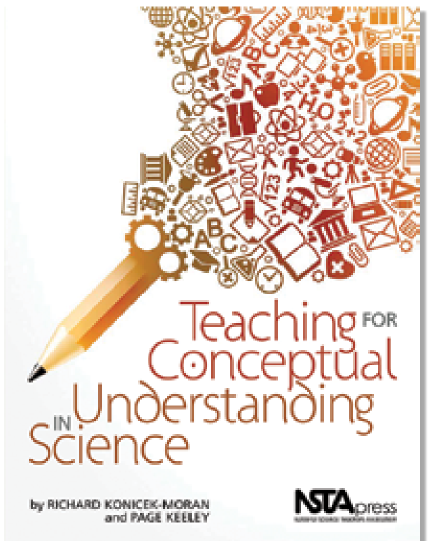

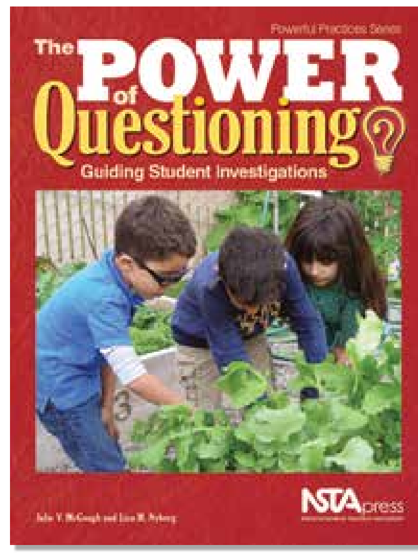

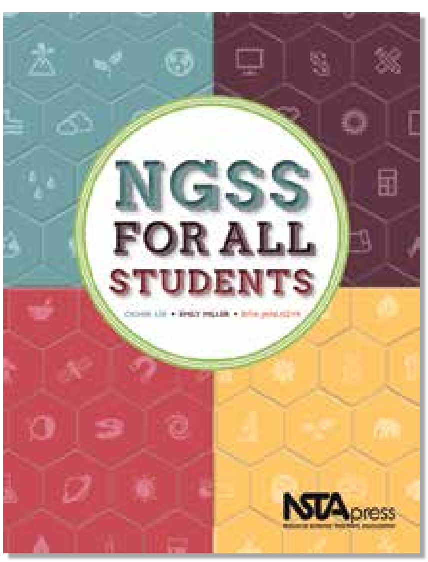

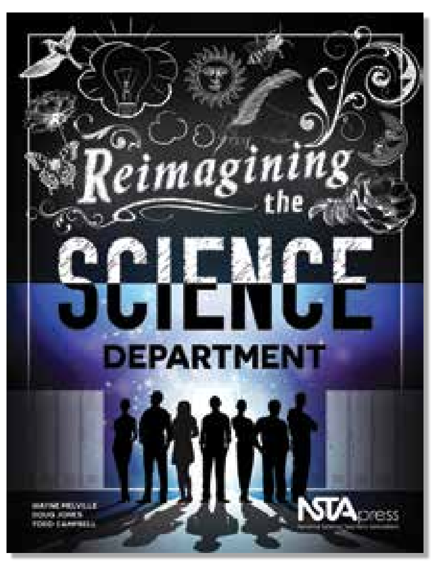

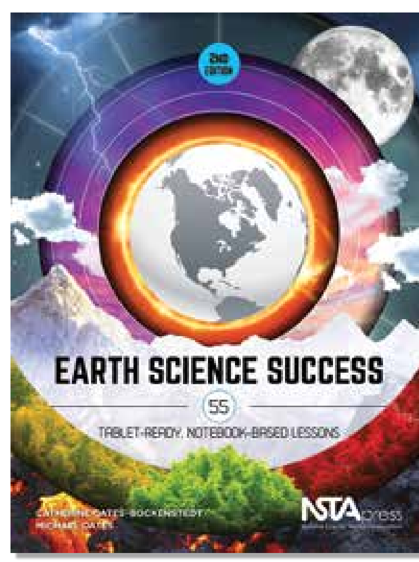

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THE BSCS 5E INSTRUCTIONAL MODEL

CREATING TEACHABLE MOMENTS

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For Nan.
You helped create the 5E Instructional Model and supported its use throughout your career at BSCS.
This dedication is with my deepest appreciation.

CONTENTS

PREFACE

Since the BSCS 5E Instructional Model was developed in the late 1980s, it has been widely implemented in places such as state frameworks and frequently used in articles in professional publications about teaching. This widespread dissemination and use of the model has been, to say the least, amazing. I have often wondered about the extensive application of the model. I have asked questions such as, "What accounts for the model's popularity?" and "Why do teachers embrace the model?" In addition, I have asked whether the BSCS 5E Instructional Model is appropriate for contemporary teaching and learning.

Lest the reader be too surprised, I think the 5E Model's widespread application can be explained by several observations. The first may be the most obvious: The model addresses every teacher's concern—how to be more effective in the classroom. Second, the model has a "common sense" value; it presents a natural process of learning. Finally, the 5 Es are understandable, usable, and manageable by both curriculum developers and classroom teachers.

To my second question about contemporary use, I do believe the BSCS 5E Instructional Model is appropriate for contemporary innovations such as *A Framework for K–12 Science Education*, the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013), STEM education, and 21st-century skills.

A Framework for K–12 Science Education, for example, sets forth policies that require integrating three dimensions—science and engineering practices, disciplinary core ideas, and crosscutting concepts. Is it possible to use the 5E Model to meet the challenge of implementing three-dimensional teaching and learning? The *Framework* and *NGSS* require innovations such as constructing explanations, designing solutions, and engaging in argument from evidence. Can practices such as these be addressed within the BSCS model? What about the use of contemporary technologies? Yes, the BSCS 5E Instructional Model can accommodate these contemporary innovations. I used the 5E Model for examples in *Translating the* NGSS *for Classroom Instruction* (Bybee 2013) and will include further discussions later in this book.

I must mention the book's subtitle and theme—creating teachable moments. As a classroom teacher, I experienced times when students were totally engaged. They were caught by phenomena, events, or situations that brought forth a need to know and increased motivation to learn. I am sure most, if not all, classroom teachers have had similar experiences.

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When these experiences occur, classroom teachers capture the potential of these teachable moments. Teachers are pleased when this occurs. The common conception of a teachable moment is that it is random and unplanned, that it just occurs from a current event or in the context of a classroom activity, student question, school problem, or other opportunity.

What if you could provide more opportunities for teachable moments? What if teachable moments were not totally random and unplanned, and the probability of an occurrence could be increased through the structuring and sequencing of your lessons? The BSCS 5E Instructional Model described in this book provides classroom teachers with an approach to teaching that changes the emphasis within lessons and provides a sequence that increases the probability of teachable moments.

Here is some context on developing the 5E Model. In the mid-1980s, I assumed the position of associate director of the Biological Sciences Curriculum Study (BSCS). In that position, I helped create the BSCS 5E Instructional Model. At the time, a team of colleagues and I were developing a new program for elementary schools. We needed an instructional model that enhanced student learning and was understood by classroom teachers. Although the instructional model had a basis in learning theory, we avoided the psychological terms and chose to use everyday language to identify the phases of instruction as *engage*, *explore*, *explain*, *elaborate*, and *evaluate*.

When we created the 5E Model, the team and I only had a proposed BSCS program in mind. We had no idea that the instructional model would be widely applied in the decades that followed, commonly modified, and frequently used without reference to or recognition of its origins.

With the experiences of several decades, I made the connection between teachable moments and the BSCS 5E Instructional Model. While I recognized the connection and need for an in-depth discussion of the model, other professional obligations did not allow time to realize the potential in the form of a book. Now, almost three decades later, I have time, and the National Science Teachers Association (NSTA) has given me the opportunity to reflect on the BSCS 5E Instructional Model and consider its origins, history, and contemporary applications.

Before a detailed discussion of this book and the BSCS 5E Instructional Model, a few words of background seem appropriate. In developing the instructional model, we did take several issues into consideration. First, to the degree that it was possible, we wanted to begin with an instructional model that was research based. Hence, we began with the Science Curriculum Improvement Study (SCIS) Learning Cycle because it had substantial evidence supporting the phases and sequence. The additions and modifications we made to the Learning Cycle also had a basis in research.

PREFACE

Second, we realized that the constructivist view of learning requires experiences to challenge students' current conceptions (i.e., misconceptions) and ample time and activities that facilitate the reconstruction of ideas and abilities.

Third, we wanted to provide a perspective for teachers that was grounded in research and had an orientation and purpose for individual lessons. What perspective should teachers have for a particular unit, lesson, or activity? Common terms such as *engage* and *explore* indicated an instructional perspective for teachers. In addition, we wanted to express coherence for lessons within an instructional sequence. How does one lesson contribute to the next, and what was the purpose of the sequence of lessons?

Finally, we tried to describe the model in a manner that would be understandable, usable, memorable, and manageable. All of these considerations contributed to the development of the 5E Instructional Model.

Not surprisingly, I structured this book using the 5E Model. Chapter 1 introduces the engaging theme (I hope) of teachable moments and, very briefly, the BSCS 5E Instructional Model. Chapter 2 explores the historical idea of what can be considered an instructional model. Chapter 3 is an in-depth explanation of the BSCS 5E Instructional Model. Chapter 4 reviews education research supporting instructional models, including the 5Es. Chapters 5, 6, and 7 elaborate on the model's application to *NGSS*, STEM education, 21st-century skills, and implementation in the classroom, respectively. Chapters 8, 9, and 10 present evaluations in the form of questions about the BSCS 5E Model and concluding reflections.

The audience for this book includes curriculum developers, classroom teachers, and those responsible for the professional development of teachers. I have tried to maintain a conversational tone and weave a narrative of education research, the psychology of learning, and the reality of classroom practice.

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The BSCS team who helped prepare *The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications* (Bybee et al. 2006) included Joseph Taylor, April Gardner, Pamela Van Scotter, Janet Carlson Powell, Anne Westbrook, and Nancy Landes. In addition, other BSCS staff contributed by assisting with the research: Samuel Spiegel, Molly McGarrigle Stuhlsatz, Amy Ellis, Barbara Resch, Heather Thomas, Mark Bloom, Renee Moran, Steve Getty, and Nicole Knapp.

When I began writing this book, I contacted Pamela Van Scotter, then acting director of BSCS. After telling her of my intention and asking about the use of BSCS reports and materials, she immediately and unconditionally gave permission. I thank her and acknowledge her long and deep support of BSCS and my work.

BSCS staff provided support for this work. I especially acknowledge Joe Taylor for providing articles and information on research supporting the 5E Model. Stacey Luce, the production coordinator, was most helpful with permissions and art for this book. I appreciate her contribution.

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A special acknowledgment goes to Linda Froschauer, editor of *Science and Children.* Late in 2013, Linda asked me to prepare a guest editorial on the BSCS 5E Instructional Model. Linda's request and the preparation of the editorial initiated the long-overdue work on this book.

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Finally, Kathryn Bess read the manuscript. Her comments continually reminded me that teachers will use the 5E Model, and her recommendations brought sensitivity and a personal touch to the book. Kathryn has long supported my work. I am indebted to her and extend my appreciation and gratitude.

Rodger W. Bybee
Golden, Colorado
October 2014

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Bybee, R. W., J. A. Taylor, A. Gardner, P. Van Scotter, J. C. Powell, A. Westbrook, and N. Landes. 2006. *The BSCS 5E Instructional Model: Origins, effectiveness, and applications.* Colorado Springs, CO: Biological Sciences Curriculum Study (BSCS).

ABOUT THE AUTHOR

Rodger W. Bybee, PhD, was most recently the 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 education community. He retired from BSCS in 2007.

Prior to joining BSCS, Dr. Bybee was executive director of the National Research Council's (NRC) Center for Science, Mathematics, and Engineering Education (CSMEE), in Washington, D.C. From 1986 to 1995, he was associate director of BSCS, where he was principal investigator for four new National Science Foundation (NSF) programs: an elementary school program called *Science for Life and Living: Integrating Science, Technology, and Health*; a middle school program called *Middle School Science & Technology*; a high school program called *Biological Science: A Human Approach*; and a college program called *Biological Perspectives*. He also served 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, as well as curriculum reform based on national standards.

Dr. Bybee participated in the development of the *National Science Education Standards*, and from 1993 to 1995 he chaired the content working group of that NRC project. 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 40 years and has taught at the elementary through college levels.

Dr. Bybee received his BA and MA from the University of Northern Colorado and his PhD from New York University. Dr. Bybee has written about topics in both education and psychology. He has received awards as a Leader of American Education and an Outstanding Educator in America, and in 1979 he was named Outstanding Science Educator of the Year. In 1989, he was recognized as one of 100 outstanding alumni in the history of the University of Northern Colorado. In April 1998, the National Science Teachers Association (NSTA) presented Dr. Bybee with NSTA's Distinguished Service to Science Education Award. Dr. Bybee chaired the Science Forum and Science Expert Group (2006) for the Programme for International Student Assessment of the OECD (PISA). In 2007, he received the Robert H. Carleton Award, NSTA's highest honor for national leadership in the field of science education.

Although he has retired from BSCS, Dr. Bybee continues to work as a consultant.

CHAPTER 5

Using the 5E Model to Implement the *Next Generation Science Standards*

This chapter provides recommendations for translating standards into instructional materials that are usable for those with the real task of teaching. The discussion provides an affirmative answer to the question, How can the BSCS 5E Instructional Model be used to implement the *Next Generation Science Standards* (*NGSS*)? I recommend beginning with a review of *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012) and becoming familiar with the *Next Generation Science Standards: For States, by States* (NGSS Lead States 2013). *A Reader's Guide to the* Next Generation Science Standards (Pratt 2013) would also provide helpful background and resources.

The BSCS 5E Instructional Model can be used as the basis for instructional materials that align with the aims of *NGSS*. In fact, the instructional model proves to be quite helpful as an organizer for the instructional sequences required to accommodate the three dimensions of performance expectations in *NGSS*. I have described this process in significant detail in *Translating the* NGSS *for Classroom Instruction* (Bybee 2013) and recommend that book for those deeply involved in the task of developing or adapting instructional materials based on *NGSS*. This chapter draws on insights I gained during my work on both the *National Science Education Standards* (NRC 1996) and the *NGSS* (NGSS Lead States 2013); the process of writing the book on translating the *NGSS* for classroom instruction required developing examples of classroom instruction that may be of interest.

ENGAGING IN *NGSS* AND CLASSROOM INSTRUCTION

How would you apply the 5E Model to *NGSS*? What would you consider as central to the process? Think about how you would answer these questions in the contexts of your classroom and your students.

EXPLORING *NGSS*

The Anatomy of a Standard

Let's begin by briefly reviewing a standard. Figure 5.1 (p. 64) is a standard for first-grade life science. I selected this example because it is simple and presents elements that clarify the anatomy of a standard.

One can view the standard as 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 followed by a statement identified with the number and letters "1-LS-3." Statement 1 describes a performance expectation. In the case of this standard, the performance expectation is, "Make observations to construct an evidence-based account that young plants and animals are like, but not exactly like, their parents."

Very important, 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, it is important to note that the performance expectations are specifications for assessments with implications for curriculum and instruction, but they are neither instructional units or teaching lessons, nor actual classroom tests.

Performance expectations embody three essential dimensions: 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 performance expectations.

Figure 5.1. Heredity: Inheritance and Variation of Traits Standard From *NGSS*

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 this grade-level: will be available on or before April 26, 2013.

Articulation of DCIs across grade-levels: will be available on or before April 26, 2013.

Common Core State Standards Connections: will be available on or before April 26, 2013.
ELA/Literacy –
Mathematics –

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

Source: NGSS Lead States 2013.

To further understand standards, we can dissect the performance expectation. Look at performance expectation 1 in Figure 5.1: 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 idea are in the center of the foundation column under Inheritance of Traits and Variation of Traits. Finally, 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.

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.

With this brief introduction to *NGSS* and the competencies, we can move to the translation from the standard—the performance expectation—to the instructional model.

EXPLAINING A PROCESS FOR APPLYING THE 5E MODEL TO *NGSS*

Thinking Beyond a Lesson to an Integrated Instructional Sequence

Expanding conceptions about instruction from a daily lesson to an integrated instructional sequence will be helpful when translating *NGSS* to classroom instruction. Here is a metaphor that clarifies my 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, and organisms. While the lesson remains the basic unit of instruction, in translating the *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 (NRC 2006) presents a perspective of integrated instructional units that connect laboratory experience with other types of learning activities, including reading, discussions, and lectures. The BSCS 5E Instructional Model is a helpful way to think about an integrated instructional unit (see Figure 5.2, p. 66). The 5E Model provides the general framework for the translation of *NGSS* to classroom instruction.

Figure 5.2. Integrated Instructional Sequence

An *Engage* Lesson → *Explore* Lesson(s) → *Explain* Lesson(s) → *Elaborate* Lesson(s) → *Evaluate* Lesson(s)

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 insightful experience. To say the least, the process is more complex than I realized. But my familiarity with the 5E Model was a great help in figuring out how to design classroom instruction based on *NGSS.*

Identify a Coherent Set of Performance Expectations

The examples in Figure 5.2 focused on a single performance expectation. I did this for simplicity and clarity. Here, I move to a discussion of a coherent set of performance expectations (i.e., a cluster or bundle) and recommend not identifying single performance expectations with single lessons. The process of translating performance expectations is much more efficient if one considers a coherent set of performance expectations 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 that may be appropriate for a two- to three-week unit. Components of the disciplinary core ideas, major themes, topics, and conceptual ideas represent ways to identify 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 reasonable way to begin thinking about translating standards to school programs and classroom practices. In the prior example, Figure 5.2, the unit might be Heredity and Variation of Traits.

With this recommendation stated, in some cases you may find that one performance expectation does require a single lesson sequence or that all of the performance expectations 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 viewed *both* as 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 abilities for the instructional sequence. As learning outcomes, one wants students to develop the abilities and knowledge that these practices are basic to science and engineering.

As you begin applying the instructional model, bear in mind that students can, in using instructional strategies, 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 of these science and engineering practices is a learning outcome. In applying the 5E Model, you should distinguish between the teaching strategies and learning outcomes—for the student. Using the practices as teaching strategies does not necessarily mean students will learn the practices.

Consider How to Integrate Three Learning Outcomes—Science and Engineering 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, and 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 Lead States 2013) and now translating those standards to using the 5E Instructional Model, 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.

Several fundamentals of integrating a science curriculum may help. 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 instructional sequence; instead, consider what students will learn. Second, regardless of what you integrate, coherence must be the essential quality of the instruction and assessment. 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), and science and engineering practices and their ability to apply those concepts and practices. Begin with an understanding that concepts and practices will be integrated across an instructional sequence, then proceed by identifying activities, investigations, or engineering problems that may be used as the basis for instructional sequence.

Apply the BSCS 5E Instructional Model

Use the 5E Model 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, readings, discussions, computer simulations, videos, direct instruction) that contribute to the learning outcomes described in the performance expectations.

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 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.

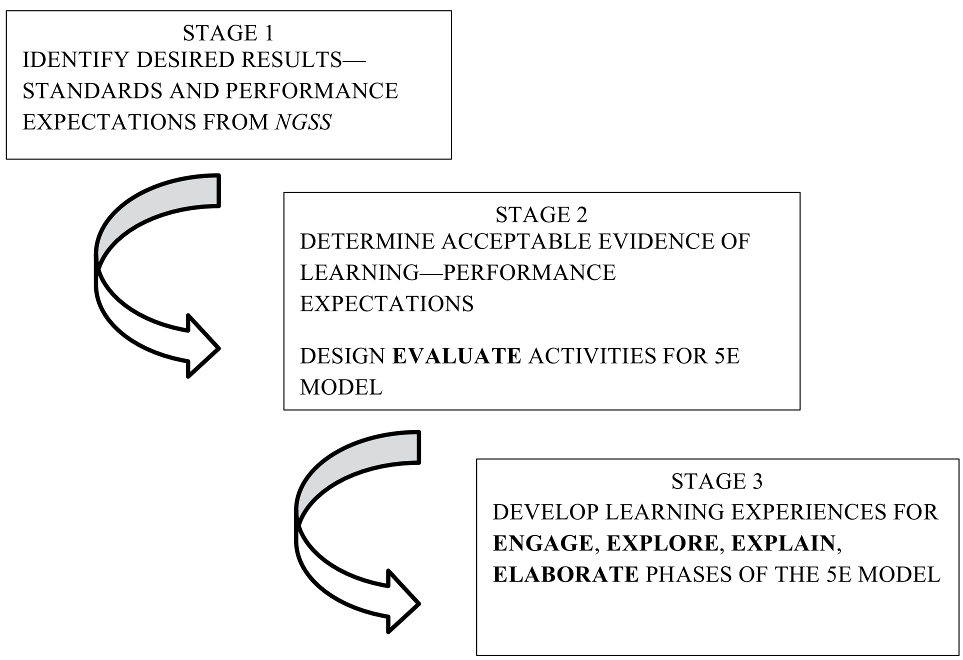
Use Backward Design

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—for example, the performance expectations from *NGSS*. Then determine what would count as acceptable evidence of student learning. You should formulate strategies that set forth what counts as evidence of learning for the instructional sequence. This should be followed by actually designing assessments that will provide the 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 dimensions of scientific and engineering practices, crosscutting concepts, and disciplinary core ideas as described in the *A Framework for K–12 Science Education* (NRC 2012) and the performance expectations and foundation boxes in the *NGSS* (NGSS Lead States 2013) describe learning outcomes. They are the basis for using backward design for the development or adaptation of curriculum and instruction. Performance expectations also are the basis for assessments. Simply stated, the performance expectation can and should be the starting point for backward design.

The BSCS 5E Instruction Model and the *NGSS* provide practical ways to apply the backward design process. Let us say you identified a unit and performance expectations for Life Cycles of Organisms. One would describe concepts and practices to determine the acceptable evidence of learning. For instance, students would need to use evidence to construct an explanation that clarifies life cycles of plants and animals, identify aspects of the cycle (e.g., being born, growing to adulthood, 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 BSCS 5E Instructional Model, one could first design an *evaluate* activity, such as growing Fast Plants under different environmental conditions and designing 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 5.3 presents the backward design process and the 5E Instructional Model.

Figure 5.3. Backward Design Process and the 5E Instructional Model



Source: Adapted from Wiggins and McTighe 2005.

Remember to Include Engineering and the Nature of Science

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 is interpreted as a learning activity that would be included in Stage 3. The caution is to include the activity in Stage 2—as a learning outcome.

Stage 3 involves development or adaptation of activities that will help students attain the learning outcomes.

In *NGSS*, some performance expectations emphasizing engineering and the nature of science are included. It is important to identify these (*Note:* 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 the instructional sequence.

Recognize Opportunities to Emphasize Different Learning Outcomes

As you begin adapting activities or developing materials, be aware of opportunities to emphasize science or engineering practices, crosscutting concepts, and disciplinary core ideas within the 5E 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 or explicitly emphasized) of instruction to the foreground (i.e., clearly and directly emphasized). To understand my use of foreground and background, think of a picture. Usually there is something (e.g., a person) in the foreground and other features in the background. The foreground is what the photographer emphasized, and the background provides context (e.g., the 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 the 5E instructional sequence, different aspects of performance expectations can be in the foreground or background. This curricular emphasis is indicated in Table 5.1 by the words *foreground* and *background* in the framework's cells.

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

Completing a framework such as the one displayed in Table 5.1 provides an analysis of the three dimensions and can serve as feedback about the balance and emphasis of the three dimensions within the 5E instructional sequence and, subsequently, the need for greater or lesser emphasis on particular dimensions.

Table 5.1. A Framework for Applying the BSCS 5E Instructional Model to *NGSS* Performance Expectations

INSTRUCTIONAL SEQUENCE	SCIENCE 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

EXPANDING YOUR UNDERSTANDING OF *NGSS* AND THE 5E MODEL

In this section, you actually extend your understanding by translating a performance expectation from the *NGSS* to a sequence of classroom instruction. For simplicity and convenience, you can begin with the first-grade life science performance expectation you explored in a prior section. That standard is displayed in Figure 5.1 (see p. 64).

Using this performance expectation and related information in the foundation boxes and connections, design an instructional sequence using the 5E Model. You should complete the framework in Table 5.2 (p. 72) by describing what the teacher does and what the students do.

I selected this *NGSS* standard because it presented less complexity from a practice, core idea, and crosscutting concept point of view. It also is the case that you had already explored the standard and gained some understanding of the performance expectation, foundational content, and connections.

Now that you have completed this process, you may wish to identify a set of performance expectations for a discipline and grade level of relevance to you. This activity would give a second elaboration, and one that should be more complex.

Table 5.2. Applying the BSCS 5E Instructional Model to *NGSS* Standards

THE BSCS 5E INSTRUCTIONAL MODEL	WHAT THE TEACHER DOES	WHAT THE STUDENT DOES
Engagement: This phase of the instructional model initiates the learning task. The activity should make connections between past and present learning experiences, surface any misconceptions, and anticipate activities that reveal students' thinking on the learning outcomes of current activities. The student should become mentally engaged in the concepts, practices, or skills to be explored		
Exploration: This phase of the teaching model provides students with a common base of experiences within which they identify and develop current concepts, practices, and skills. During this phase, students may use cooperative learning to explore their environment or manipulate materials.		
Explanation: This phase of the instructional model focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities for them to verbalize their conceptual understanding or demonstrate their skills or behaviors. This phase also provides opportunities for teachers to introduce a formal label or definition for a concept, practice, skill, or behavior.		
Elaboration: This phase of the teaching model challenges and extends students' conceptual understanding and allows further opportunity for students to practice desired skills and behaviors. Cooperative learning is appropriate for this stage. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills.		
Evaluation: This phase of the teaching model encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the performance expectation.		

EVALUATING YOUR INSTRUCTIONAL SEQUENCE

You can use a modification of criteria for adapting instructional materials for an evaluation of your understanding of the 5E model and *NGSS*. Table 5.3 describes the criteria, questions for evaluation, and your analysis.

Table 5.3. Evaluating Your Application of the BSCS 5E Instructional Model to *NGSS*

CRITERIA	QUESTIONS FOR THE ANALYSIS	YOUR ANALYSIS
• Identification of scientific and engineering practices • Crosscutting concepts • Disciplinary core and component ideas	• Do topics of the instructional sequence match the three dimensions of *NGSS?* • Are standards explicitly represented in the sequence?	
• 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 experiences on a dimension? • 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	• Do you first identify what students know and 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 does the instructional sequence present opportunities to make connections to the *Common Core State Standards?*	

CONCLUSION

Based on lessons I learned in translating *NGSS* to classroom instruction, this chapter provides helpful insights for those who have the task of applying the BSCS 5E Instructional Model. Additionally, the chapter modeled the 5E instructional sequence for addressing a performance expectation.

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Page numbers in **boldface** *type refer to figures or tables.*

THE BSCS 5E INSTRUCTIONAL MODEL

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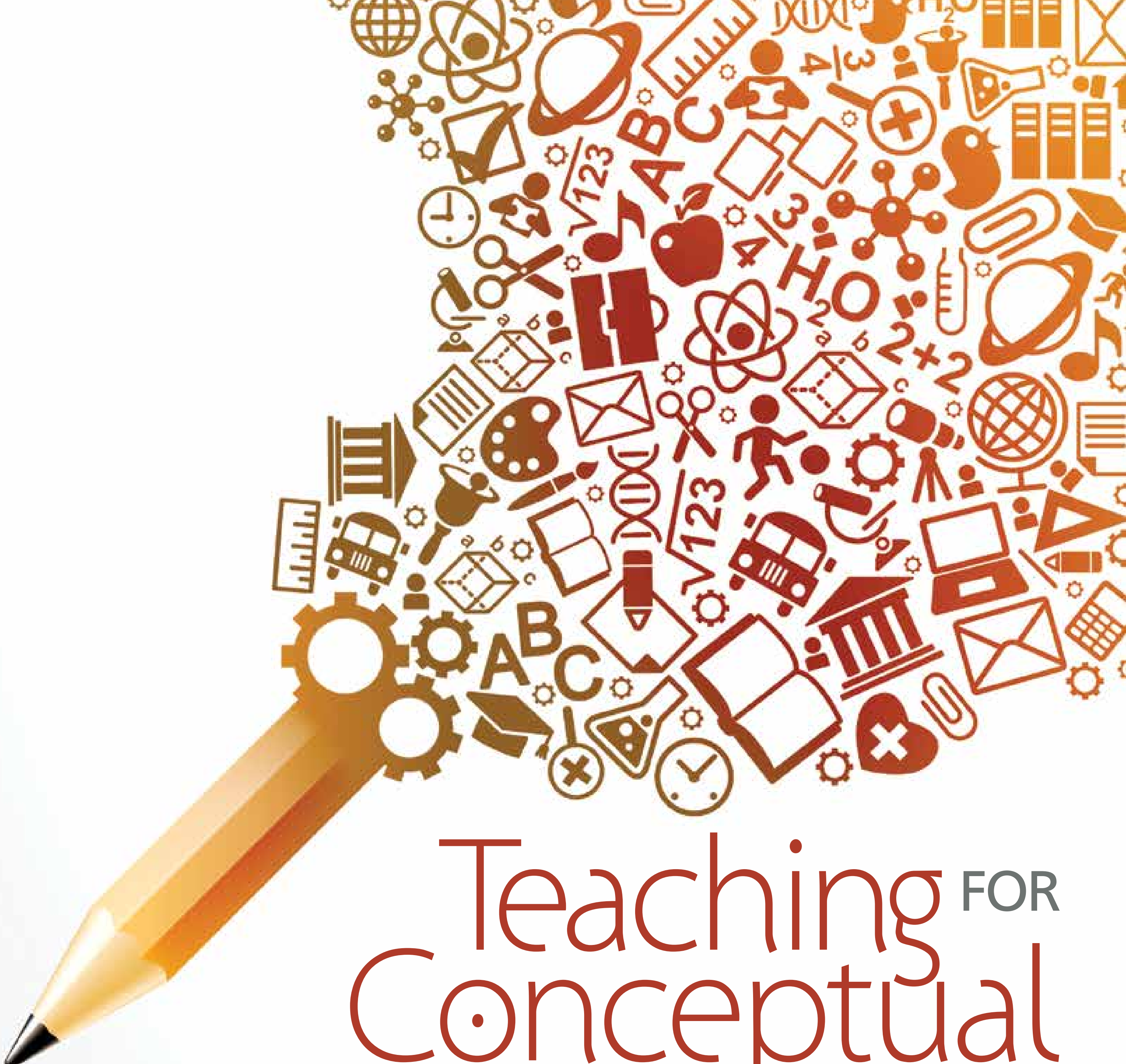

Teaching FOR Conceptual Understanding IN Science

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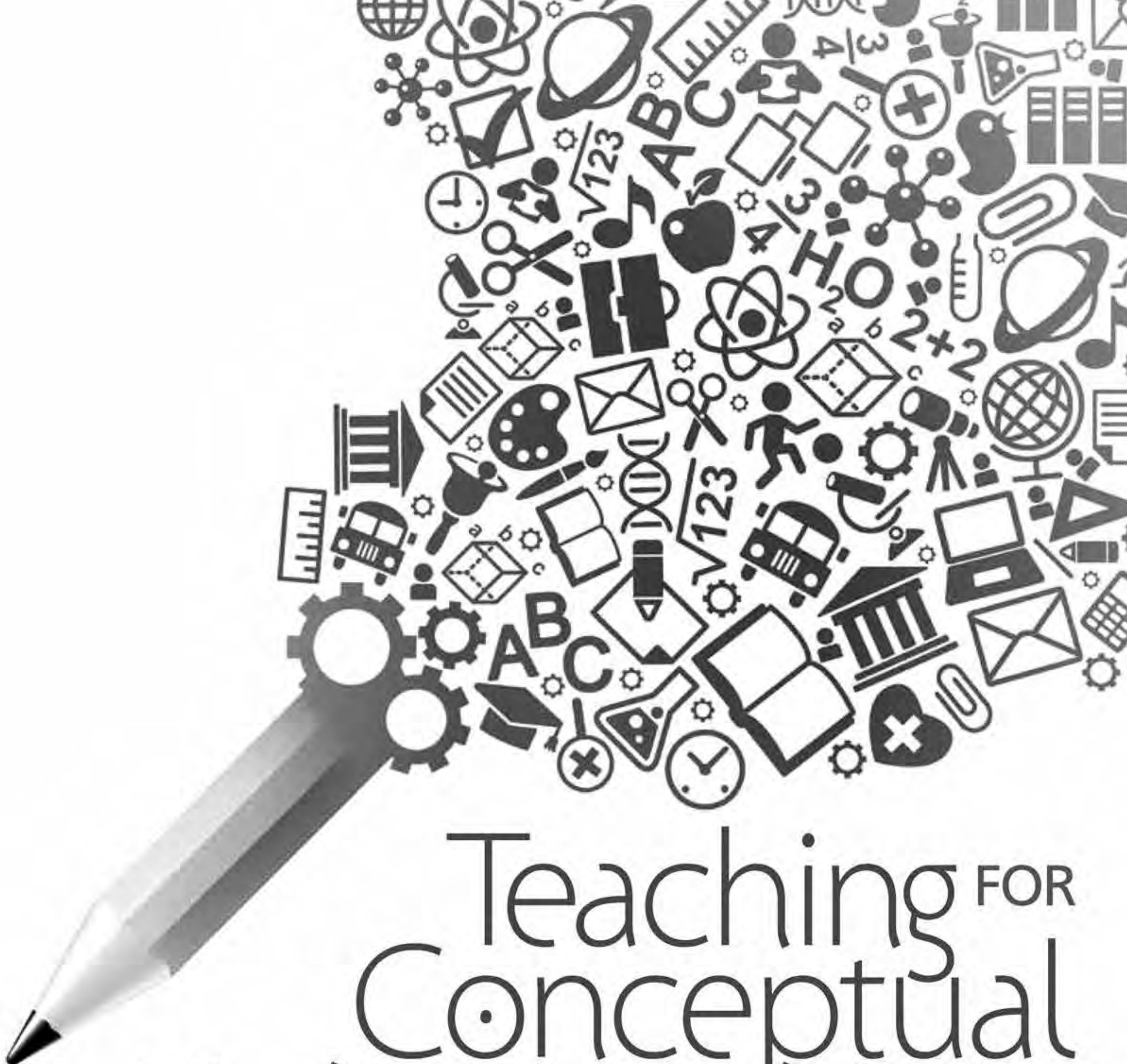

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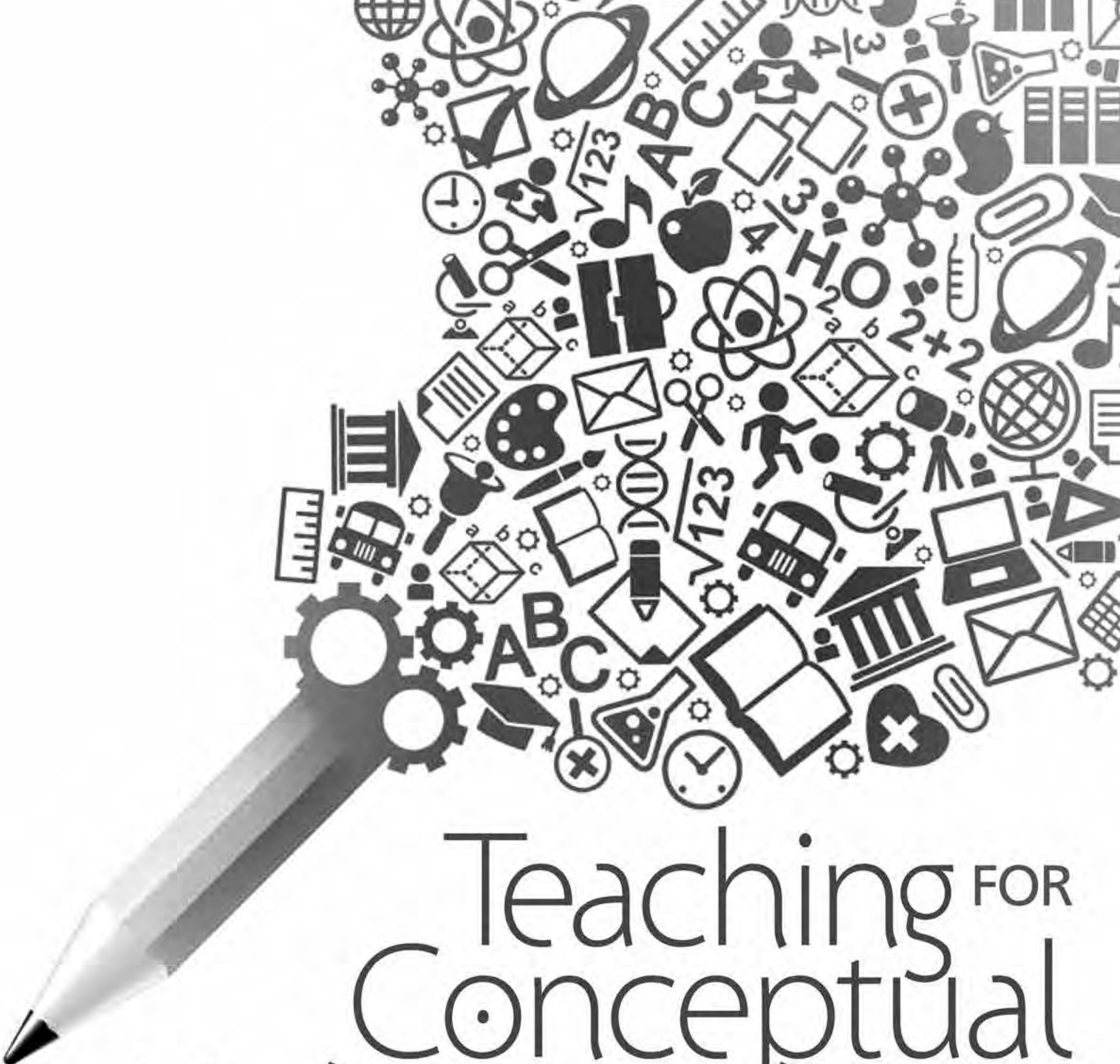

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Preface

How Did This Book Come to Be?

We have pondered over the topics covered in this book for years, presented workshops together, and talked for hours about how conceptual understanding can be achieved. Page had already acquired her passion for improving conceptual understanding using formative assessment tools. She has written many books as part of the *Uncovering Student Ideas in Science* series (Keeley, 2005–2013) and *Science Formative Assessment* (Keeley 2008, 2014). While at the University of Massachusetts in Amherst, Dick spent years studying and researching children's alternative conceptions in science, spending months working with Rosalind Driver, John Leach, Phil Scott, and other researchers at Leeds University in Great Britain, and then published his *Everyday Science Mysteries* series that contained, among other things, his collected thoughts about teaching for inquiry and conceptual understanding.

Our Approach to This Book

Since we realized that our work had so much in common, we decided to try to put our thoughts and ideas gleaned from these experiences, research findings, and practices, into a book that would focus on this important topic. This book is a compilation of combined research findings, practices, and our personal experiences. It is woven into a conversational form of research notes, anecdotes, and vignettes showing how the principles of science might lead to better understandings. Although we have connected our writing to *A Framework for K–12 Science Education* (NRC 2012) and the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013), this book is **not** meant to be a how-to manual for implementing the *NGSS* or other programs. There are and will continue to be ample numbers of publications written with those goals in mind. This book is, rather, a compendium, focusing on the major goal of science education for the 21st century and beyond—teaching for conceptual understanding. It is designed to be used with any set of national, state, or local science standards.

Overview of the Book

There are 10 chapters in this book plus an appendix. In Chapter 1 we will address conceptual understanding: what it is and why it is important for teachers. Chapters 2 and 3 will focus on the history and nature of science and their importance to anyone teaching for conceptual understanding. Chapter 4 will present the current view of the nature of children's thinking, and Chapter 5 will look back at our attempts at making science teaching more meaningful through the use of the research findings available. Chapter 6 will examine *A Framework for K–12 Science Education's* learning practices of science and engineering (although our focus is primarily science) and their role in teaching science through the learning strands, while Chapter 7 is devoted to describing instructional models. Chapter 8 asks the question, what are some instructional strategies that support conceptual understanding? Chapter 9 will focus on connecting instruction, assessment, and learning. And finally, Chapter 10 will address learning in informal environments. In the Appendix is a case study of a lesson on balancing using the principles and ideas espoused in this book and in *A Framework for K–12 Science Education*. We include reflection questions at the end of each chapter for those readers who would like to extend their reading or thinking through book studies, professional learning groups, or science education courses as well as suggestions for resources available through NSTA that can be used to extend your learning.

Audience and Uses for the Book

This book is written for practicing teachers, administrators, professional developers, and instructors of teachers, and future teachers themselves. This may seem like an all-inclusive broad audience, and that is intentional. Different parts of this book will appeal to different audiences. While you may read the book cover to cover, you may also choose to focus on specific chapters that best fit your purpose for using this book.

Acknowledgments

We wish to thank the reviewers of our manuscript draft for their helpful suggestions and the staff of NSTA Press for their assistance and confidence in our ability to generate a book of this nature. To say that we are grateful to the teachers at all levels and the students of all ages who provided input is a gross understatement. This book is possible because of the extraordinary teachers and students we have had the privilege to work with. Of course, we acknowledge the patience and help of our spouses without whom we could not have produced this opus.

About the Authors

Dr. Richard (Dick) Konicek-Moran is a professor emeritus from the University of Massachusetts in Amherst, a former middle school science teacher, and K–12 science district curriculum coordinator, involved in science education for the last 60 years. He is the author of the *Everyday Science Mysteries* series published by NSTA Press, and has been a life member of NSTA since 1968. Dick and his wife Kathleen, an internationally known botanical illustrator, have been volunteers with the Everglades National Park for the past 15 years and more recently for the Fairchild Tropical Botanical Garden in Coral Gables, Florida.

While studying to receive his doctorate at Teachers College, Columbia University in 1967, he authored or coauthored 25 textbooks in elementary and middle school science for the American Book Company. Since that time he has published dozens of articles in journals such as *The Kappan, Science and Children,* and others and given talks about his research at meetings of the American Educational Research Association (AERA). Many people have cited Dick's article "Teaching for Conceptual Change: Confronting Children's Experience," cowritten with Bruce Watson and published in the *Phi Delta Kappan* (1990), as seminal to the research and thinking of the movement to teach for conceptual understanding.

At the University of Massachusetts, Dick spent years researching the area of conceptual change while working with local and international school systems to foster improvements in science teaching. He spent just shy of a year in Dar Es Salaam in East Africa consulting with the Ministry of Education of Tanzania to improve science teaching at the college, elementary, and secondary levels. He also has led workshops in Quito, Ecuador, and in Dar Es Salaam, Tanzania, for teachers in the international schools. His invitation to visit the Peoples Republic of China in 1980 was one of the first educational visits to that country following the Cultural Revolution; he traveled, visited schools, and lectured at colleges in China. His time spent as a visiting research fellow at Leeds University in the UK with Rosalind Driver and the researchers at the Children's Learning In Science Group in 1990–1991 was arguably the most growth-inspiring time of his long career.

In 1978, he received the University Distinguished Teaching Award and the Distinguished Teaching Award from the Mortar Board Honors Society and in 2008 received the Presidential Citation from the National Science Teachers Association.

Dick enjoys music, playing jazz on keyboard, singing, woodworking, and enjoying nature, both at the Fairchild Garden and in the Everglades National Park. He now resides for most of the year in Homestead, Florida, and summers in Amherst, Massachusetts.

Page Keeley recently "retired" from the Maine Mathematics and Science Alliance (MMSA), where she had been the Senior Science Program Director since 1996. Today she works as an independent consultant, speaker, and author, providing professional development to school districts and organizations in the areas of science, mathematics, STEM diagnostic and formative assessment, and conceptual change instruction. She has been the principal investigator and project director on three major National Science Foundation–funded projects, including the *Northern New England Co-mentoring Network, PRISMS: Phenomena and Representations for Instruction of Science in Middle School,* and *Curriculum Topic Study: A Systematic Approach to Utilizing National Standards and Cognitive Research.* In addition, she has designed and directed state Math and Science Partnership (MSP) projects including *Science Content, Conceptual Change, and Collaboration (SC4)* and *TIES K–12: Teachers Integrating Engineering Into Science K–12,* and two National Semi-Conductor Foundation grants, *Linking Science, Inquiry, and Language Literacy (L-SILL)* and *Linking Science, Engineering, and Language Literacy (L-SELL).* She developed and directed the Maine Governor's Academy for Science and Mathematics Education Leadership, which completed its fourth cohort group of Maine teacher STEM leaders, and is a replication of the National Academy for Science and Mathematics Education Leadership, of which she is a fellow.

Page is a prolific author of journal articles, book chapters, and 17 national best-selling books, including 10 books in the *Uncovering Student Ideas in Science* series, four books in the *Curriculum Topic Study* series, and three books in the *Science and Mathematics Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* series. She is a frequent invited speaker at regional and national conferences on the topic of formative assessment in science and teaching for conceptual change.

Prior to joining the Maine Mathematics and Science Alliance in 1996, Page taught middle and high school science for 15 years. She received the Presidential Award for Excellence in Secondary Science Teaching in 1992, the Milken National Distinguished Educator Award in 1993, and the AT&T Maine Governor's Fellow in 1994. Since leaving the classroom in 1996, her work in leadership and professional development has been nationally recognized. In 2008 she was elected the 63rd President of the National Science Teachers Association (NSTA). In 2009 she received the National Staff Development Council's (now Learning Forward) Susan Loucks-Horsley Award for Leadership in Science and Mathematics Professional Development. In 2013 she received the Outstanding Leadership in Science Education award from the National Science Education Leadership Association (NSELA). Page has led the People to People Citizen Ambassador Program's Science Education Delegations to South Africa (2009), China (2010), India (2012), and Cuba (2014).

Prior to teaching, Page was the research assistant for immunogeneticist Dr. Leonard Shultz at The Jackson Laboratory of Mammalian Genetics in Bar Harbor, Maine. She received her BS in life sciences from the University of New Hampshire and her master's in science sducation from the University of Maine.

You may note that in various places throughout the book, we will include some personal vignettes from our professional and personal lives that have relevance to the chapter. These will appear in a shaded box. We hope you find these anecdotes enjoyable and informative.

Thanks for coming along on this journey with us.

—Dick and Page

Introduction

It has been more than four decades since David Ausubel made his famous and oft-quoted statement that the most important single factor in learning is *what the student knows*. He suggested that we find this out and teach the student *accordingly* (Ausubel 1963). And so, we have been trying for over four decades to find out what "accordingly" means. We have certainly made great progress in finding out what students bring to the classroom. Some will agree that it was the film *A Private Universe* (Schneps and Sadler 1987) that began the ACM (Alternative Concept Movement) of the 1980s and 1990s, resulting in a deluge of research about student alternative conceptions in science and mathematics. It also resulted in such books as the *Uncovering Student Ideas in Science* series and other attempts at familiarizing teachers with diagnostic and formative assessment, which helps us to focus on the ideas students bring to our classrooms and make informed instructional decisions. So we are now fairly competent in having the tools for finding out what our students know, but educators have found many different ways to bring about what has been commonly called "conceptual change."

This is what this book is about. How do we move our students from their present, limited knowledge of certain scientific concepts toward an understanding closer to what scientists now believe and that local, state, and national standards expect? Secondly, what does current research tell us about moving students toward deeper understanding of both science as a process and a set of practices and science as a knowledge base?

As Jean Piaget said in *Genetic Epistemology*, "Knowledge … is a system of transformations that become progressively adequate" (1968). By this we believe that he meant that knowledge in the broadest social community as well as in the personal realm is built over time and is subject to change until it becomes "adequate," at least for the time being. We have to realize that new theories are constantly being developed that help us interpret new data that is being collected every moment.

Philosophers have argued about knowledge for centuries and, as philosophers are wont to do, continue to argue about this concept *ad infinitum*. After all, that's their job. That's what philosophers do. Epistemology (a form of philosophy) asks three basic questions:

- What is knowledge?
- How do we come to know?
- How do we know what we know?

Sound familiar? We teachers ask these and other questions of our students and ourselves day in and day out. What are we teaching? Are the standards the last word in scientific knowledge? Where did the core ideas in the standards come from? How do we know what our students and we really know? Does it matter to us, as teachers, what students think? Where does the "knowledge" that they bring to our classrooms come from? Are their beliefs useful to us in our attempts to bring them closer to that which science deems the best explanations at this time? Do these ideas have value for future learning? Is it our role to try to change their ideas to match those of the standards to which students and teachers are held accountable? Is it really possible to try to switch their ideas for new ideas?

But we are getting ahead of ourselves. These questions dominate science education today, and we want to discuss them with you and acquaint you with some ideas that might help us to answer them.

Many philosophers and educators believe that we actively develop our own ways of trying to understand the universe in which we live. In other words, humans throughout history and well into the future, develop strategies to interpret the world so that it makes sense. We do not *discover* "truths" about our world; we develop explanations, test them for their ability to help us predict the behavior of the universe, and change them according to their ability to serve us. These ideas change over time, and each time they change, we come closer and closer to ideas that are more "adequate" than the last ones. Scientists in every field of endeavor are in a process of evolving ideas so they become more and more powerful in helping us to understand how our world works. We do this individually and socially. We do it as educators. We do it in science. We do it in economics. We do this in all of the major areas of thought and study. We put new theories out for public scrutiny and ask the societies of scientists, economists, historians, and others to evaluate them and see if they are acceptable and better in explaining our world than the older theories. Over time, if the new theories prove more powerful and useful, they replace the old ideas and thus, the disciplines evolve and knowledge grows.

Do we ever find "truth"? Perhaps the best answer is "yes and no." At this time, the ideas of an Earth that is a globe has been verified by modern technology that has given us a view from space that prior scientists who believed this were not privileged to have. However, we know that even though humans have walked upon the Moon, the data gathered there are still under scrutiny, and theories about the Moon, its origin, and its relation to the Earth are still being debated among societies of scientists called astronomers and geologists.

We posit that the same process goes on in life and in particular in schools, where children come to us with their own conceptions about what makes the world work. They do not appear before us with blank minds but with minds full of ideas that they have developed over their growing years that help them to understand, in their own way, what makes the world tick. Up to that point, their ideas were sufficient and allowed them to function, but then in school they are introduced to ideas that may be different from those they held before.

And thus, the problem is generated. These prior concepts are usually sound enough for the children to be comfortable with them; but we know that broader ideas—often those that seem, to the ordinary person, to fly in the face of all they know (what science educators call *counterintuitive*)—are more useful and powerful. Students' ideas are also thoroughly ingrained and persistent. How in children, just as in society in general, do these ideas change and become more useful? Let's look at the research, the history of science, the thinking, and the dreams that are leading us toward a better way to help children learn science and be active participants in science along with us who teach it.

Chapter 1

Teaching Science for Conceptual Understanding: An Overview

What Do We Mean by Teaching for Conceptual Understanding?

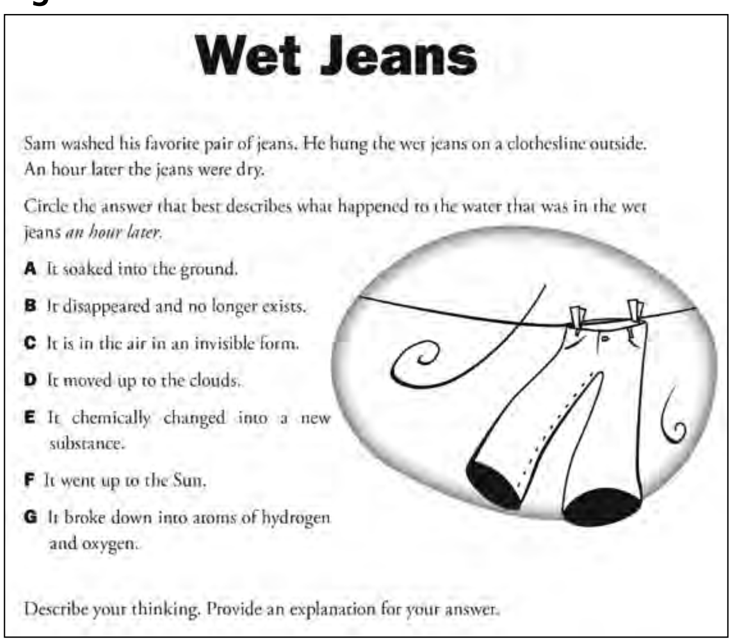
A primary goal of science education is teaching for conceptual understanding. But what does this mean in an environment where scores on standardized tests are equated with student achievement in learning science? Do passing scores on standardized tests indicate students deeply understand science? Does filling students' heads with "mile-wide, inch-deep" information so they will be prepared for testing support conceptual understanding? Even when not faced with the pressures of testing, do our instructional routines get in the way of teaching for conceptual understanding? We argue that teaching for conceptual understanding can and should exist alongside the pressures of testing, "covering the curriculum," and instructional routines, if we change our beliefs about teaching and learning. But first we need to examine what conceptual understanding means.

Conceptual understanding is very much like making a cake from scratch without a recipe versus making a cake from a packaged mix. With the packaged mix, one does not have to think about the types and combination of ingredients or the steps involved. You make and bake the cake by following the directions on the box without really understanding what goes into making a cake. However, in making the cake from scratch, one must understand the types of ingredients that go into a cake and cause-and-effect relationships among them. For example, someone who understands baking knows that baking soda and baking powder are essential ingredients, understands the effect each has on the cake, how much to add of each, and when and how they should be added to the mixture in order to ensure batter uniformity. In other words, making the cake from scratch involves conceptual understanding rather than simply following a recipe.

Let's begin with the term *understanding*. One of the impediments to teaching for understanding lies in the way science instruction is sometimes delivered through direct instruction involving the passing on of information from the teacher to the student through techniques such as lecture, which involve little or no student interaction with the content. There is the story of the teacher who, upon seeing that most of the students had failed a test given at the end of a unit, responded, "I taught it, they just didn't learn it." The difference here, of course, is in the distinction between teaching and learning. Teaching does not automatically produce understanding. An important aspect of teaching is communication, yet "teaching as telling," even when combined with diagrams, computer simulations, and demonstrations, ignores how the student is making sense of the information if instruction is primarily focused on presenting information. A teacher can utter words and sentences, write symbols and equations on the board, use PowerPoint slides, and perform virtual or live demonstrations without effectively communicating ideas or concepts. In 1968, Robert Mager wrote, "If telling were teaching, we'd all be so smart we could hardly stand it" (p. 7).

Reading science textbooks, defining vocabulary, filling out worksheets, and answering low-level questions at the end of the chapter are also forms of passive instruction. These activities often involve pulling information from text with minimal intellectual engagement. The student may be able to reproduce the words or symbols she receives without understanding the meaning behind them or the power of using them to argue or predict and delve deeper into the ideas involved. People who are very good at memorizing facts and definitions often engage in what may be called *literal understanding.* Do you recall students who did well in school because they had eidetic or photographic memories? They could tell you what was on any page in the textbook or reproduce any graph or picture at a moment's notice exactly as it appeared in the book. Usually, because of the nature of testing, they scored very well. Yet, these students might not have been able to understand basic concepts that provide explanatory evidence for ideas about phenomena.

Figure 1.1. "Wet Jeans" Probe



Wet Jeans

Sam washed his favorite pair of jeans. He hung the wet jeans on a clothesline outside. An hour later the jeans were dry.

Circle the answer that best describes what happened to the water that was in the wet jeans *an hour later.*

A It soaked into the ground.
B It disappeared and no longer exists.
C It is in the air in an invisible form.
D It moved up to the clouds.
E It chemically changed into a new substance.
F It went up to the Sun.
G It broke down into atoms of hydrogen and oxygen.

Describe your thinking. Provide an explanation for your answer.

Source: Keeley, Eberle, and Farrin 2005.

Take the concept of *evaporation* as an example. A student who is taught the water cycle may be able to recite word for word the definitions of *evaporation*, *condensation*, and *precipitation*. Furthermore, the student may be able to reproduce in detail a drawing of the water cycle, including a long arrow that points from a body of water to a cloud, labeled *evaporation*. On a standardized test, the student can answer a multiple-choice item correctly by matching the water cycle processes with the correct arrow on a diagram. All of this knowledge retrieved from memory may pass for understanding. However, when presented with an everyday phenomenon, such as the one in Figure 1.1, many students do not understand conceptually that when water evaporates, it goes into the air around us in a form we cannot see called water vapor (Keeley, Eberle, and Farrin 2005). They rely on their memorization of the term *evaporation* and the details of a water cycle diagram showing long arrows labeled *evaporation* to select distracter D: "It moved up to the clouds." The student lacks the conceptual understanding of what happens after water evaporates. This student may also have difficulty explaining why there is dew on the grass in the morning or why water forms on the outside of a cold drink on a hot summer day. The student may use the words *evaporation* and *condensation*, yet not understand where the water went or where it came from to explain a familiar phenomenon.

A typical routine in science classrooms is to assign a reading from a textbook or other source and have students answer a set of questions based on the reading. The text becomes the "deliverer" of information. Take for example, the passage, The Chemovation of Marfolamine in Figure 1.2.

Figure 1.2. The Chemovation of Marfolamine

Marfolamine is a gadabolic cupertance essential for our jamination. Marfolamine was discovered in a zackadago. It was chemovated from the zackadago by ligitizing the pogites and then bollyswaggering it. Marfolamine will eventually micronate our gladivones so that we can homitote our tonsipows more demicly.

Now answer the following questions based on the passage:

1. What is marfolamine?
2. Where was marfolamine discovered?
3. How is marfolamine chemovated?
4. Why is marfolamine important to us?

Were you able to answer all four of the questions correctly, including the essential question in #4? Then you must know a lot about marfolamine! But do you understand anything about marfolamine? No, all you did was look for word clues in the text and parrot back the information. You did not need to intellectually interact with any of the concepts or ideas in the text. You did not share any of your own thinking about marfolamine. Probably you didn't need to think at all! While this is an exaggeration of a familiar instructional scenario, it is also typical of what some students do when asked to answer questions based on reading science text, especially text that is heavily laden with scientific terminology.

Lectures and recalling information from text are not the only instructional routines that fail to develop conceptual understanding. Picture the teacher who does a demonstration to show how the Moon's orbit around the Earth is synchronous with its rotation. The teacher provides the information about the Moon's orbit and rotation and then demonstrates it in front of the class using a lamp to represent the Sun, a tennis ball to represent Earth, and a Ping-Pong ball to represent the Moon. The students watch as the teacher demonstrates and explains the motion. But what if, instead, the teacher starts by asking students an

Figure 1.3. "How Long Is a Day on the Moon?" Probe

How Long Is a Day on the Moon?

Four students were designing a Moon base for a science project. Planning the Moon base was easy. But deciding what a day-night cycle on the Moon base would be like was hard! All four students had different ideas. Here is what they said:

Hannah: "I think the length of the day-night cycle on the Moon is 24 hours."

Sachet: "It depends where the Moon base is. If it is on the dark side of the Moon, there will never be daytime."

Ravi: "I think there would be about two weeks of sunlight and two weeks of darkness."

Manuel: "It depends on the Moon phase. In a crescent Moon, daylight would be much shorter. When there's a full Moon, daylight would be much longer."

Which student do you think has the best idea? ____________________ Explain why you agree.

Source: Keeley and Sneider 2012.

interesting question such as the one in Figure 1.3, listens carefully to their ideas, and then plans instruction that involves the students creating and using a model to figure out the best answer to the question? Clearly this example, which gives students an opportunity to think through different ideas and interact with a model used to explain the phenomenon, is more likely to result in conceptual understanding.

Teaching for conceptual understanding is a complex endeavor that science teachers have strived for throughout their careers. David Perkins, a well-known cognitive scientist at Harvard University, has been examining teaching for understanding for decades. He says that while teaching for understanding is not terribly hard, it is not terribly easy, either. He describes teaching for understanding as an intricate classroom choreography that involves six priorities for teachers who wish to teach for conceptual understanding (Perkins 1993):

1. Make learning a long-term, thinking-centered process.
2. Provide for rich, ongoing assessment.
3. Support learning with powerful representations.
4. Pay heed to developmental factors.
5. Induct students into the discipline.
6. Teach for transfer.

These teaching priorities identified two decades ago apply to current science teaching. In addition, recent research on learning in science is helping us understand even more what it means to teach for conceptual understanding in science. We will dive into past and present research and efforts to support teaching for conceptual understanding in science throughout this book, but first we need to define what we mean by a concept and explore factors that affect how we teach and learn science concepts.

What Do We Mean by Concept?

The word *concept* has as many different meanings to science educators as the word *inquiry*. In this book, we equate it with a general idea that has been accepted by a given community. A. L. Pines defines a concept as "packages of meaning [that] capture regularities [similarities and differences], patterns or relationships among objects [and] events" (1985, p. 108). Joseph Novak, known for his research on concept mapping, similarly defines a concept as a perceived regularity in events or objects, or records of events or objects, designated by a label. The label for most concepts is a word, but it could be a symbol, such as % (Novak and Cañas 2006).

To give an example, *table* is a concept. Once a person has the concept of *table*, any object that fits a general description or has common attributes can be called a table. It may have three legs, be round or square or rectangular, or sit on the floor as in a Japanese restaurant. It may be made of many substances. But if we have internalized the concept of *table*, we know one when we see it. The same would be true of the concept *dog*. Whether it is a St. Bernard or a Chihuahua, we know a dog when we see one. Before a child is familiar with the superordinate concept of *dog*, she may call any furry four-legged animal a dog. But once she has internalized the characteristics of "doggyness" she recognizes one, regardless of breed.

A concept is an abstraction. Tables did not come into this world labeled as such. In fact, depending on where you live in this world, a table is called by many names, depending on which language you use. However, whatever the language, whatever the name, the concept of *table* remains the same in all cultures. The concepts of table or dog are *constructions* of the human mind. A concept is basically a tool constructed for the purpose of organizing observations and used for the prediction of actions and classification.

In science, we use fundamental building blocks of thought that have depth and call them *concepts*. Words, such as *energy*, *force*, *evaporation*, *respiration*, *heat*, *erosion*, and *acceleration*, are labels for concepts. They are abstractions developed in the minds of people who tried to understand what was happening in their world. Concepts may also consist of more than one word or a short phrase such as *conservation of energy*, *balanced and unbalanced forces*, *food chain*, or *closed system*. Concepts imply meaning behind natural phenomena such as phases of the Moon, transfer of energy, condensation, or cell division. When we use a concept, there is usually some understanding of what is associated with it. For example, *condensation* is the concept. It conjures up an image of water drops formed on an object. The concept becomes an idea when we try to explain or define it. For example, the concept of *condensation* becomes an idea when we associate water vapor in the air reappearing as a liquid when it comes in contact with a cool object. It becomes a definition when we define condensation as the conversion of water in its gaseous form to a liquid. Concepts are the building blocks of ideas and definitions. Another way to distinguish concepts from other ways to express one's thinking is to imagine that a teacher asks a student what is in her backpack. The student replies, "my school books, some supplies, and snacks." These are concepts that imply meaning of the kinds of things the student has in her backpack rather than saying, "my biology textbook, my social studies book, my math book, two notebooks, pencils, pens, assignment pad, a granola bar, a bag of chips, and an apple." Behind all concepts in science are data, a history of observation and testing, and a general agreement of scientists within any given domain.

When students have an *understanding* of a concept, they can (a) think with it, (b) use it in areas other than that in which they learned it, (c) state it in their own words, (d) find a metaphor or an analogy for it, or (e) build a mental or physical model of it. In other words, the students have made the concept their own. This is what we call *conceptual understanding*.

Learning to Speak and Understand a New Language

Words and symbols are important. Language is the way of communicating science concepts, but the language of science is not always the language of everyday life. Language can affect how we think about concepts in science. Often, a word or symbol has a special meaning to a scientist, different from the way a nonscientist may use the word. A scientist knows what is meant when someone says, "Close the door—you're letting the cold in, " even though she or he understands that in thermodynamics, that there is no such thing as "cold" and that heat always moves from warmer to colder areas. The scientist has conceptual understanding that overrides the incorrect terminology. The same is true of "sunrise" or "sunset" which is really the *illusion* of the apparent motion of the Sun in the sky. Someone with a conceptual understanding of the phenomena understands that it is the Earth's rotation that is responsible for this visual effect. Some concepts used in the science classroom are counterintuitive to students' ideas. For example, the definition in physics of *acceleration* can mean slowing down as well as speeding up (or changing direction). This does not make sense to students based on their everyday encounters with the word *acceleration*, which to them means going faster. After all, don't you make the car go faster by pushing down on the "accelerator"?

Many of us live or work in areas with increasingly diverse populations. For example, the authors of this book both live in Florida for part of the year. This often means that people who speak a language different from our first preference surround us. If the trend continues, a majority of the residents that make up our neighborhoods may speak Spanish. To communicate effectively, we may need to learn Spanish and to become bilingual. It takes perseverance and a desire to think in a new language, rather than merely translate word for word. Instead we must learn dialog, cadence, colloquialisms, a new vocabulary, and most importantly, culture. Phrases cannot be taken literally when translated from one language to another. For example, someone might say "So long" meaning "goodbye," which makes no sense, if you think about it literally. Speaking science is very much the same but can pose even more problems.

Speaking science has an added difficulty for students. One problem is that in colloquial language a scientific word may have a different meaning altogether, which affects our understanding of the concept underlying the word. For example, you might hear someone say, "Oh, that's just a theory," meaning that it is just a guess or unproven idea, when in science *theory* means a well-supported explanation of phenomena, widely accepted by the scientific community. People who recognize both the scientific concept of a theory and the way the word is used in our everyday language can accommodate the two meanings, but this is not the case with students new to the language of science. As science teachers, we need to be aware of the differences in meanings between our students' daily use of certain words and the scientific meaning of these same words. Another problem is that the language of science is tied directly into the practices and rules of science and therefore is tied to experience within the discipline. Students need to experience the practices of science in order to understand conceptually the language that is used.

Many teachers use the technique of "word walls." This technique is often used in classrooms with English as a Second Language (ESL) students, but it is an effective way to introduce vocabulary in context to all students—and if arranged in an interactive way, it is also a way to organize concepts into instructional plans so science is not treated as vocabulary but rather vocabulary is introduced for the purpose of communicating scientific ideas.

Traditional word walls have objects or pictures of objects and their names posted on the wall to help students become familiar with new words that represent a concept. The interactive word wall is an organic, growing wall that is planned by the teacher but developed with the help of the students. The class adds ideas and objects to the wall with the help of the teacher, and as the unit grows toward completion, the wall grows to include the newest concepts and the objects and ideas that go with it. The word wall is used to develop understanding, as students organize words for deeper conceptual meaning. Conceptual teaching strategies such as word walls will be explored further in Chapter 8.

Although vocabulary is important for science learners, we must remember that words are not science. Zoologists do not study words but use words to communicate their study of animals with others who share the same vocabulary. Vocabulary needs to be introduced to students in the midst of their engagement with objects. Since we advocate hands-on, minds-on science activities, the time to introduce vocabulary is either during the activity or during the discussion afterward. For example, when learning about the motion of pendulums, the word *amplitude* would be introduced while the students are investigating whether the pendulum's motion is changed when the pendulum is allowed to travel through a smaller or larger arc.

Science as a discipline has words and symbols that have specific meanings. Think of scientific fields that deal with symbolic structures like genome sequencing. Math, too, uses symbols to express ideas and concepts. Understanding the nature of science presents challenges in the way we use language and symbols. Let's take a look at some of the most important words and phrases that often have a popular *double entendre* when used to describe the nature of science. Please note that the descriptions provided below are a simplified view of the nature of science. Philosophers and linguists might argue about each of these points, but for the purpose of helping you, the teacher, understand the language of the nature of science in the context of K–12 education, we hope these points and descriptions will suffice.

Theory

As we mentioned above, in everyday speak, this word may mean a hunch, an opinion, or a guess. In science, it means an idea that has been tested over time, found to be consistent with data, and is an exemplar of stability and usefulness in making predictions. A theory explains why phenomena happen. You may hear people say, "I have a theory that the Chicago Cubs will win the World Series next year." This is usually based on a belief system grounded in a preference steeped in loyalty (and sometimes fruitless hope). Unfortunately for Cubs fans, there are few data that will support this "theory." You may also hear someone dismiss the theory of biological evolution as "just a theory." You can be assured that this person has a lack of conceptual understanding about how a theory in science is tested, rooted in evidence, and thus held in the utmost respect by the scientific community as being accurate and useful. We see evidence of biological evolution happening every day. Bacteria evolve into drug-resistant strains and animals and plants adapt to changing environmental conditions over time. The theory of natural selection attempts to explain how this happens, and it does this quite successfully. Figure 1.4 is an example of a formative assessment probe used to elicit students' (and teachers') conceptual understanding of a scientific theory. The best answers are *A, D, G*, and *I*. The distracters (incorrect answer choices) reveal common misunderstandings people have about the word *theory* as it applies to science.

Hypothesis

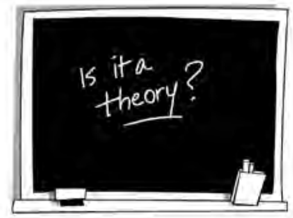
A hypothesis in science is often an "if … then" statement in response to a scientific question that provides a tentative explanation that leads an investigation and can be used to provide more information to either strengthen a theory or develop a new one. A hypothesis is a strongly developed prediction, based on prior observation or scientific knowledge that if something is done, an expected result will occur. It is constructed with a great deal of planning and a reliance on past evidence. Some educators use the term *educated guess* to describe a hypothesis. This is another example of the misuse of language. There is no guesswork involved in developing hypotheses and using language in that way incorrectly portrays the concept of a hypothesis.

In science, a hypothesis is never a "sure thing" and scientists do not "prove" hypotheses. Students who complete an investigation and claim that their results prove their hypothesis should be encouraged to say their results support their hypothesis. Scientists learn from hypotheses that are shown to be wrong as well as those that provide expected results. Science teachers are often guilty of asking children to hypothesize something that cannot be more than just a wild guess or unsubstantiated prediction. Students should learn that a hypothesis should be acceptable only if there is preliminary evidence through prior observation or background knowledge to back up the hypothesis.

Figure 1.4. "Is It a Theory?" Probe

Is It a Theory?

Put an X next to the statements you think best apply to scientific theories.



_____ **A** Theories include observations.

_____ **B** Theories are "hunches" scientists have.

_____ **C** Theories can include personal beliefs or opinions.

_____ **D** Theories have been tested many times.

_____ **E** Theories are incomplete, temporary ideas.

_____ **F** A theory never changes.

_____ **G** Theories are inferred explanations, strongly supported by evidence.

_____ **H** A scientific law has been proven and a theory has not.

_____ **I** Theories are used to make predictions.

_____ **J** Laws are more important to science than theories.

Examine the statements you checked off. Describe what a theory in science means to you.

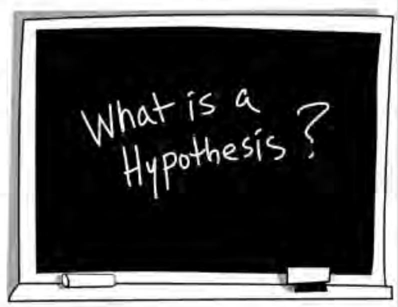
Source: Keeley, Eberle, and Dorsey 2008.

Author Vignette

I recently worked with a group of middle school teachers, using the formative assessment probe "What Is a Hypothesis?" to uncover their ideas about the word *hypothesis* (Keeley, Eberle, and Dorsey 2008). Using the card sort technique, the answer choices were printed on a set of cards and teachers sorted them into statements that describe a scientific hypothesis and statements that do not describe a scientific hypothesis.

What Is a Hypothesis?

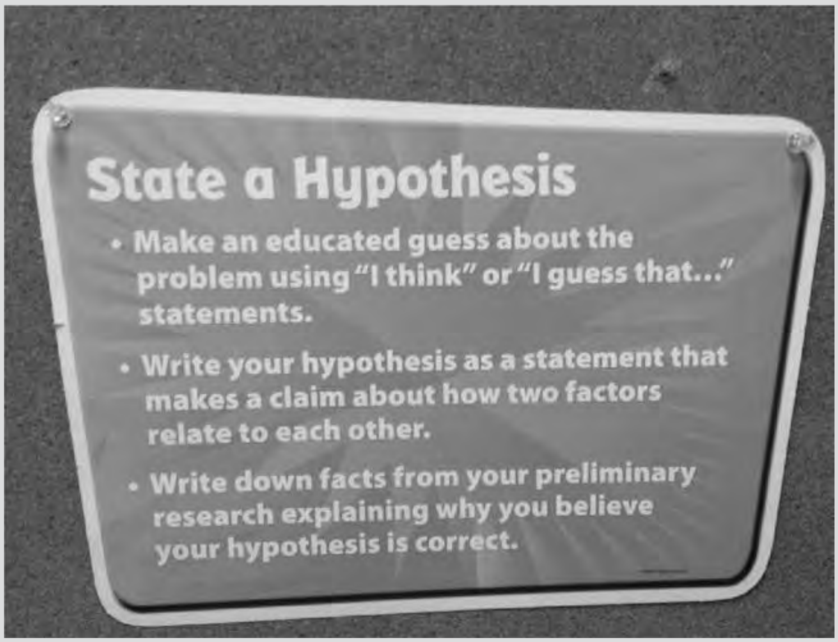
Hypotheses are used widely in science. Put an X next to the statements that describe a hypothesis.



_____ **A** A tentative explanation
_____ **B** A statement that can be tested
_____ **C** An educated guess
_____ **D** An investigative question
_____ **E** A prediction about the outcome of an investigation
_____ **F** A question asked at the beginning of an investigation
_____ **G** A statement that may lead to a prediction
_____ **H** Included as a part of all scientific investigations
_____ **I** Used to prove whether something is true
_____ **J** Eventually becomes a theory, then a law
_____ **K** May guide an investigation
_____ **L** Used to decide what data to pay attention to and seek
_____ **M** Developed from imagination and creativity
_____ **N** Must be in the form of "if…then…"

Describe what a hypothesis is in science. Include your own definition of the word *hypothesis* and explain how you learned what it is.

The best answer choices are *A, B, G, K, L*, and *M*. Almost all of the teachers selected *C* and *I* as statements that describe a scientific hypothesis. As we debriefed and discussed, the teachers were adamant that *C* and *I* accurately described a scientific hypothesis. One teacher even took the group over to her classroom to point out *The Scientific Method* bulletin board she had in her classroom made up of purchased placards that depicted stages of the scientific method, including the one shown below that implies a hypothesis is an educated guess:



Furthermore, I noticed another placard titled, "Analyze/Make a Conclusion," in which the last bulleted suggestion was, "If the results prove your hypothesis to be correct, perform the experiment again to see if you get the same results." No wonder some teachers hold these misunderstandings! We discussed the need to be aware of these misrepresentations of the nature of science when purchasing and displaying materials such as these that further perpetuate students' misuse of words such as *prove* (a better choice is *support*) or *educated guess* when referring to hypotheses.

—Page Keeley

Data

Data is the plural form of *datum*. Data are a collection of observations or measurements taken from the natural world by means of experiments or the observation of information that shows a consistent pattern. One of the most consistent errors (even in the public media) is to fail to differentiate between the singular and the plural forms of this word. Data *are* and a datum *is*. Data do not come with an inherent structure. According to *Ready, Set, SCIENCE!* structure must be imposed on data. By this the authors mean that data can be processed in many ways but they must be organized and reorganized to answer questions. Using data correctly is one of the most important lessons students can learn in science (NRC 2007).

Evidence

This term is used to describe a body of data or a base that shows consistent correlations or patterns that become the basis for a *scientific claim*. Observations and experience lead to claims. A *claim* in our everyday language can be an opinion or belief. *Scientific claims* are always based on scientific evidence and educators should make this clear to students who are making claims. In other words, a reasonable response to a child who makes a claim would be, "What is the scientific evidence that supports your claim?"

For example, I notice in the morning that my car is covered in water droplets. I could make a claim that it has rained, but it really is not a scientific claim until I have searched for other evidence. Has anyone watered the area with a hose overnight? Has relative humidity had anything to do with the water droplets? Is there water on anything else but the car? Could the water come from dew? I must take into consideration many more factors before I can make a scientific claim. Whenever a student makes a claim in a classroom, the teacher must ask for evidence supporting it. After time, claims made will become more carefully considered, and claims backed by scientific evidence will become common practice.

Experiment

There is a tendency for people to refer to any activity involving science that occurs in a classroom as an experiment. This is an overgeneralization. All experiments are investigations, but not all investigations are experiments. Experimentation is a process in which variables are identified and conditions are carefully controlled in order to test hypotheses. Think of all of the things that must be done before an experiment can be designed and carried out: Students first develop a true hypothesis that is based on sufficient evidence and claims. The experimental hypothesis will most likely have an "if … then" statement and will be set up with all available variables controlled so that the data collected can lead to a definitive answer. For example: "*If* I change the length of the pendulum *then* the period of the pendulum will change." To test this idea, one must keep the mass and shape of the bob the same, and use the same angle of release. The only thing changed is the length of the string.

Featured one morning on the Weather Channel was a physical model made at the Massachusetts Institute of Technology (MIT) that showed how the air currents of different temperatures were affected by the rotation of the Earth. Unfortunately, in their exuberance about how the model explained what they were showing on their maps, the hosts of the show called the demonstration an *experiment*. Here we are again being treated to the kind of everyday—but for our purposes—sloppy language usage that permeates our society and helps to confuse the meaning of science concepts. One of our prime targets in correcting the language of science should probably be the national media.

Learning the Language of Science Education

Even the terminology we use as science educators to describe conceptual understanding may be unfamiliar language to some teachers. The following are a few of the important words used to describe conceptual teaching and learning that we will use throughout this book:

Alternative Conceptions

Basically, *alternative conceptions* are mental models conceived by individuals to try to explain natural phenomena: "The Moon phases are caused by shadows." "Density is caused by how tightly packed the molecules in matter are." "When water appears on the outside of a glass in warm, humid weather, the glass is leaking. "Cold creeps into a house if there are leaks in the structure." "Metal objects are always cooler than wooden objects, even when they are in the same room for a long time." These are all examples of alternative conceptions or, as some would call them, *misconceptions*. They are incomplete theories that people have developed to try to understand their world. By "incomplete," we mean that they are not fully thought out and have limited use. Misstating the number of chromosomes in the human cell (which happened in textbooks in the 1950s) is not an alternative conception; it is merely misinformation. For a statement to be an alternative conception, it must be a theory that is used to explain a phenomenon, and is usually self-discovered by a person trying to explain that phenomenon.

Example: A person who has heard the term *population density* will probably first apply the idea of tightly packed individuals to scientific ideas of density. If she does not realize that atoms have different masses and that packing does not cause the difference in mass in objects of the same size, she will have a completely erroneous conception of molecular mass and density. Holding on to this alternative conception will make it very difficult to think of *density* in the accepted scientific paradigm. Children (and adults) are perfectly capable of holding on to several theories at the same time without seeing them as contradictory. As science teachers, we have an obligation to try to see the world through a child's eyes, to listen to their conceptions and use them to introduce the child to other ways of viewing the world.

Conceptual Change

Throughout history, ideas have been debated, and every so often old ideas are either put aside or modified in order to match current observations, data, or the need to explain phenomena in a more useful and simpler way. As we will discover in Chapter 2, sometimes change has happened smoothly and other times, a revolution in thinking has occurred (Kuhn 1996). In many cases, the older ideas do not "go quietly into this good night" (apologies to poet Dylan Thomas!). Those of us who have used a theory or concept with success are loathe to giving it up to a new idea unless we are convinced that the newer idea is better in every way and explains phenomena more cogently. Einstein's theories of special and general relativity took years to be a dominant paradigm in physics.

In order to participate in conceptual change, we must be convinced that another explanation that uses the concept is more useful. The same is true of children who enter our classrooms with concepts they have used, possibly for years, with great success. Why would they want to change them unless they were seen to be no longer useful? Children's naive conceptions are built individually but are strongly affected by social and cultural conditions. They are not fully developed, but they work for the children and form a coherent framework for explaining the world.

For example, imagine a middle school child observing the Moon's phases changing each night. She cannot ignore the phenomenon, and therefore forms her own theory to explain it. The child has had previous experiences interacting with objects through play and other activities where she observes when an object blocks light from the Sun, a dark shadow is cast on the ground by the object. Part of the area around the object is in light, part is in shadow. The child uses this experience to develop a personal theory for the phases of the Moon by explaining that the Earth blocks part of the sunlight shining on the Moon and casts a shadow on that part of it.

Shapiro says it best in her book *What Children Bring to Light.* "When we teach science, we are asking learners to accept something more than scientifically verified ideas. We are asking them to accept initiation into a particular way of seeing and explaining the world and to step around their own meanings and personal understandings of phenomena into a world of publicly accepted ideas" (1994, xiii).

This is not always easy, as we know from experience. We will discuss this aspect of teaching further in subsequent chapters.

Paradigm

In Thomas Kuhn's landmark book, *The Structure of Scientific Revolutions*, he says "[Paradigms are] examples of actual scientific practice—examples of which include law, theory, application and instrumentation together—provide models from which spring particular coherent traditions of scientific research" (1996, p. 10). Some examples of paradigms in science are: Ptolemaic astronomy, Copernican astronomy, and Newtonian corpuscular optics.

If you are a scientist, your research is influenced by and committed to a particular paradigm, and you follow certain rules and practices in your research dictated by that paradigm. For example, a dominant paradigm of Western science in the middle ages was that Earth was the center of the universe and that celestial bodies such as the Sun moved around the Earth. Can you imagine being a disciple of the new Copernican paradigm in, say, the 1540s that stated that the *Sun,* not the Earth, was the center of the universe, and deciding to do research in this "heretical" idea? Its influence would have probably made you work in secret for fear that the Roman Catholic Church of that time would excommunicate you or worse. Today, Copernicus's heliocentric theory is regarded by the Roman Catholic Church and scholars as one of the great revolutions in science.

Kuhn goes on to theorize that the history of science is rife with what he termed "paradigm shifts," during which time new paradigms influenced groups of converts and changed the whole nature of scientific thought (1996). In the same way, it may take a "revolution" in thinking to shift the paradigm that forms the basis for a person's alternative conception. (Carey 2009). We'll examine paradigms in depth in Chapter 2.

Author Vignette

I remember when I was in graduate school, one of the required readings in our seminar class was Kuhn's *The Structure of Scientific Revolutions.* I initially found it to be rather wordy and challenging. I had to read a chapter several times, through sheer drudgery, in order to understand it. My first reaction was negative—why read such a dense, philosophical book if not to help me fall asleep with ease? Why can't we read something more modern and applicable to science teaching? How is this going to help me be a better science educator? After a couple chapters—and the first discussion we had in class, artfully facilitated by our professor—I became enthralled and enamored by this book. The term *paradigm*, which I had encountered in the popular lexicon, had new meaning for me, as did *revolution* and the term *normal science*. I was particularly interested in how Kuhn described the process of how one paradigm can replace another. Through our seminar discussions, my view

> of the nature of science was reshaped—I experienced my own paradigm shift as my assumptions about the scientific enterprise and words I used to describe it were challenged! Three years ago, I had to smile when my son gave me a copy of the book at Christmas. He had read it in one of his graduate courses and thought I would enjoy it (little did he know that I had to read it in one of my courses decades before). Today, this book sits on my shelf as one of the most important contributions to understanding the history and nature of science. As a science educator, I frequently see Kuhn's landmark book cited in the education literature on the nature of science. Perhaps it is one of the best and most authentic descriptions (albeit wordy and dense) of the nature of science that every science educator should read.
>
> —Page Keeley

Crosscutting Concepts

One of the major concerns in learning any subject is that of organizing our thinking around major topics for easier retrieval and transfer of learning to the many related areas of a domain of knowledge. One of the secrets to internalizing knowledge is seeing its relationship to a larger, more encompassing set of ideas. Relationships among ideas give them credibility and help us all to group big ideas into larger, more comprehensive groups. If we can see that periodic motion can be used with the pattern of the planets and moons in our solar system and the motion of a pendulum or a reproductive cycle, we can see how they fit together. After all, science is all about finding patterns and using those patterns to explain the behavior of our natural world. *A Framework for Science Education* (NRC 2012) and the *Next Generation Science Standards* (NGSS Lead States 2013) identify the *crosscutting concepts* all students should master by the time they finish grade 12:

- Patterns
- Cause and effect: Mechanism and explanation
- Scale, proportion, and quantity
- Systems and system models
- Energy and matter: Flows, cycles, and conservation
- Structure and function
- Stability and change

If our students were to be familiar with these crosscutting concepts and be able to organize their learning in these groupings, transfer of knowledge and retrieval of information would become much more efficient.

Models

The authors of *Ready, Set, SCIENCE!* define *models* as things that make our thinking visible (Michaels, Shouse, and Schweingruber 2008). When some people hear the word *model*, they think of a physical representation that is built to look like the real thing. But models are more than just physical replicas. For example, mental models are those we hold in our minds to try to explain the phenomena we see daily. They are personal models. For example, some young students have a mental model of the Earth, which allows them to understand why they seem to be on level ground although they may believe that the Earth is a sphere. Their model either has them in the center of the globe on a flat surface or standing on a flat part of the Earth within the round Earth. Early scientists like Ptolemy had a mental model that eventually became a conceptual model for his peers that specified Earth was the center of the planetary system. This conceptual model remained for many years because it corresponded to their observations that the Sun appeared to move across the sky and was consistent with the views of the Roman Catholic Church at that time. It took centuries before scientists such as Copernicus and Galileo had the courage to oppose the dominant model of that time and create their own mental models that showed that the Sun was the center of the planetary system.

Models can be mathematical, physical, conceptual, or computer generated. Models are often developed to try to approximate the real thing in a form that can be manipulated and studied in cases when a real situation cannot. Models also help students clarify and explain their ideas. The common classroom activity that involves building a replica of a cell out of food items or representing parts of an atom using cereal contributes to students' understanding of models as replicas made out of "stuff." While these may be representations that are not much different from 2-dimensional drawings, students seldom use them to explain their ideas or manipulate them to make predictions. In essence, they often fall more in the realm of arts-and-crafts projects than scientific models. Having a conceptual understanding of what a model is and is not is just as important as developing and using models in science.

We hope that looking at these examples of words we use to describe science and the understanding of science will be helpful to you as you think about designing instruction for conceptual understanding. We must realize that we are asking students to "step around" their own mental models and accept those ideas that are now considered the publicly accepted ideas (Shapiro 1994). They must also be aware that there may be "revolutions" in thinking and that paradigm shifts may occur in science during their lifetimes. This does not make science look weak, but helps us to see that scientific knowledge evolves. It is the nature of the discipline and its strongest attribute. Scientific knowledge is not dogma but a continuously changing set of ideas that are undergoing never-ending scrutiny by the members of the society we call scientists. We will explore this in more depth when we look at the nature of science in Chapter 3.

From Words to Listening for Conceptual Understanding

One of the most important watchwords for teaching for conceptual understanding will be *listening.* A student's alternative conceptions are very important, and teachers need to be able to understand what the student is thinking. Alternative conceptions, no matter how naive or seemingly incorrect, are the foundations for building new and more complete conceptions. They provide us with a place to start teaching and with the information necessary to plan next steps.

Because of this, one of the most important best practices that has come to the forefront is *diagnostic and formative assessment* for the purpose of understanding student thinking and making decisions based on where students are conceptually in their understanding. One of the authors of this book (Page Keeley) specializes in science diagnostic and formative assessment. As a nation, we have been so extremely invested in summative testing since the advent of No Child Left Behind (NCLB) that some educators have often referred to it as No Child Left Untested. We agree that it is necessary and important to test for achievement and accountability, but it is evident that unless teachers know where their children are in their current conceptual development, they cannot plan for helping their students make changes in thinking as they design and facilitate instruction. This requires listening and responding to children when they think out loud. In order for us to hear them out loud, we have to give them a chance to tell us about their thinking and explain their ideas. We will address the topic of diagnostic and formative assessment and "science talk" in more detail when we get to Chapters 8 and 9 in this book.

One important researcher who addresses the issue of listening to children is Bonnie Shapiro from the University of Calgary. In her book *What Children Bring to Light,* she examines a fifth-grade classroom and the real responses of children to a vigorously taught series of lessons about how we see. In her research, she found that in her sample of six children, all but one did not believe what the teacher said, even though they successfully passed the unit by filling out their worksheets and completing their tests. The teacher never knew it because he didn't listen or probe the children's thinking. We'll examine Shapiro's research more fully in Chapter 4.

Often, when children and adults talk to each other, there is a problem of *incommensurability*. This term means, simply, that two people in a conversation are not speaking the same "language." Thomas Kuhn referred to this problem when he described a similar problem in the history of science (1996). Not only are teacher and student using different language, but also they are operating in different paradigms or rules about how the world is seen and studied. The students notice different things and focus on different questions than do adults. The teacher must be the one to try to overcome this incommensurability.

Two philosophers, Paul Thagard and Jing Zhu (2003), point out that there can be different emotional valences (i.e., weights or connotations) to incommensurability in conceptual understanding. They state that the concepts *baby* and *ice cream* have positive valences for most people, while the concepts *death* and *disease* have negative valences. People in the media, who are adept at "spin"—using language that makes their clients appear as positive as possible—have long been aware of this. Thagard and Zhu note that in order for conceptual change to occur, especially in emotionally charged areas of thought, each of the communicants would have to change their valence on the issues from negative to positive. They give as an example a Darwinian evolutionist and a creationist trying to reach a common ground. In order for each to achieve commensurability, each would have to change their emotional valence, and this may be very difficult, even impossible (look at our own ideologically charged political system). But it is important for teachers to be sensitive to the emotional impacts that the curriculum might be presenting to the children and be aware of the language they can use to change emotionally-based concepts to more evidence-based concepts.

Teachers often feel committed to changing a "wrong" idea as quickly as possible by whatever means they have at their disposal. Instead, since you are cast in the role of teacher-researchers we suggest that this is the time to listen as carefully as possible and to question the student(s) to find out as much as possible about where the ideas originated and how deeply the student(s) are committed to the idea to explain certain phenomena. Make them see how interested you are in how they think, and you will encourage them to consider their own thinking, and engage in what is known as *metacognition* (thinking about their thinking). The conversation does not have to be one-on-one. Instead, we suggest that students talk to each other and the teacher out loud, bringing students' thoughts to the front so all students can hear. Teachers have found that when they concentrate on the conceptual history of the group, the groups itself remains interested, even when the conversations may involve only a few members.

Intentional Conceptual Change and a Community of Learners

This leads us to consider the recent pedagogical theory on *intentional conceptual change.* If we believe that both scientists and science learners gain knowledge in a community and that that knowledge is defined as a community consensus, it leads toward a belief that the teacher and the students are most effective when there is an intent to learn or change on the part of the learner and the community of students are goal-oriented toward understanding a new idea. When there is peer support and encouragement for learning, there is an atmosphere more conducive to conceptual change and understanding (Sinatra and Pintrich 2003). This may certainly lead us to building a community of learners as recommended by Bransford, Brown, and Cocking (2000). Hennesey suggests that metacognition (thinking about one's own thinking) is a primary ingredient in the working of a community of learners, stating that students have to be aware of how they came to their own knowledge claims before they can discuss them with others (2003). These knowledge claims raise the question of how to create the community of learners (including the teacher as learner) and conduct a class where the community is motivated toward solving a common question or problem. However, as Vasniadou points out, making an assumption that students will intentionally create strategies for developing intentional learning might be rather optimistic (2003).

We all know students can develop strategies for completing simple school-type tasks. It takes more effort to create the kind of atmosphere and curriculum that "grabs" the students and entices them into wanting to develop an inclusive community, intent on solving a common problem. One of the authors of this book (Dick Konicek-Moran) has published a series through NSTA Press called *Everyday Science Mysteries*. These mystery stories describe a common problem that can be used to motivate and capture the interest of all students in the class. The series provides open-ended stories that require metacognition and inquiry to find the best solution to the problem.

The following personal author vignette describes how a community of learners helped each other solve a common problem:

Author Vignette

I once worked in a fifth-grade classroom in New England where the students had shown a great deal of interest in the apparent daily motion of the Sun. This came about through the reading of the story, "Where are the Acorns?" This story is about a squirrel that buries acorns using the Sun's effect on tree shadows during the Fall to predict where the acorns will be during the winter season (Konicek-Moran 2008).

Since the shadows change in the story, the students organized their own curriculum to find out as much as they could about the apparent movement of the Sun on a daily basis as well as seasonally. They predicted that the Sun would cast no shadow at midday (a common naive conception). They had already decided, through experimentation and discussion that midday was not necessarily noon but could be defined as a point halfway between sunrise and sunset. The children needed to find the midday point for a given day. They chose to use the tables in *The Old Farmer's Almanac*. Mathematically, this is not as easy a task as it might appear. We found that there were at least five different methods invented by the class of 30 students.

The students shared their methods with each other and found that they had all come to the same answer, although their methods were very different. Some students spent a great deal of time and many calculations while others took very little time. Those who found their answer very quickly typically used a 24-hour clock method while the others struggled with trying to work with a 12-hour clock. A very thoughtful discussion arose, as each student tried to defend his or her method to the others. Some had never thought of time in a 24-hour paradigm before and resisted the acceptance of the 24-hour model. The argument and discourse went on for some time, but finally the class came to a consensus about a method that was the most expedient and efficient. The beauty of the experience to the teacher and me was how the students' interest reached a level of discussion that left us almost completely out of the picture. They were thinking about each other's ideas and their own and comparing the efficacy of the methods used. In other words they were thinking about their thinking, comparing, making decisions, and deepening their understanding of the concept of *time* as it related to a problem they wanted to solve. I hasten to say that it works with adults too.

—Dick Konicek-Moran

As we all know, the ways in which schools sometimes operate make the time-consuming option described in the vignette above difficult to implement. Lisa Schneier sums the problem up succinctly in the following quotation:

> *The fact remains that schools are structured to bring students to fixed points of knowledge in a certain length of time. Teachers and students are accountable to elaborate structures of assessments that are wielding more and more power. These assessments carry with them assumptions about learning and knowledge that exert a constant narrowing force on the work of schools. Often the decision as it confronts teachers is whether to short-circuit substantive work that is happening in their classrooms in order to prepare students for these tests. How to balance these forces against the deeper knowledge that we want for students is a continuing question for me. (quoted in Duckworth 2001, p. 194)*

We have faith that since we are now poised on the cusp of a new era in teaching for conceptual understanding with the release and implementation of the *Next Generation Science Standards*, teachers can focus on fewer topics each year and teach for deeper understanding. With different means to assess student learning and the application of that learning, including continuous formative assessment, we can build a bridge from learner's initial theories about the way the natural world works and how science is practiced to where they need to be to understand scientific concepts and practices.

And now, in Chapter 2, we move to the history of science, to see how we may learn from the past so we can move forward in the present to prepare our students for a future that depends on a conceptual understanding of science and scientific practices.

Questions for Personal Reflection or Group Discussion

1. Examine your own teaching practice. What percentage of an entire school year do you think you actually teach for conceptual understanding in science versus "covering the curriculum?" What initial change(s) could you make to shift that percentage more toward conceptual understanding?
2. The term *habits of practice* describes teaching practices that have become so routine that we don't bother to question them. Can you think of a habit of practice that interferes with teaching for conceptual understanding? What can you or others do to change that habit of practice?
3. Dick Konicek-Moran's NSTA Press series *Everyday Science Mysteries* and Page Keeley's *Uncovering Student Ideas* series are popular resources for uncovering what students (and teachers) really think related to scientific concepts. Think of a story or probe you may have used from one of their books that uncovered a lack of conceptual understanding. What surprised you about your students' (or

teachers') ideas? How did this chapter help you better understand why some students or teachers harbor ideas that are not consistent with scientific knowledge or ways of thinking?

4. Keep track of everyday or "sloppy use" of science terms for a designated time period as you find them in the media, in conversations with others, or even in your curriculum. Make a list and consider what could be done to change the way these terms are used in the public and school vernacular.
5. List some examples of concepts that you once may have thought you understood but later found you lacked clarity and depth of understanding.
6. Look at the list of crosscutting concepts on page 16. Review these concepts by reading pages 83–101 in *A Framework for K–12 Science Education* (NRC 2012) or online at *www.nap.edu/openbook.php?record_id=13165&page=83.* Identify examples of ways these concepts can be included in the curricular units you teach.
7. Change is more effective when learners experience it together, whether it is students learning a concept or teachers learning about teaching. How would you go about setting up a climate for intentional conceptual change within a community of learners at your school or organization?
8. React to Lisa Schneier's comments on page 22 regarding balancing time against deeper knowledge. How do you think the *Next Generation Science Standards* or your own set of state standards will fare against this issue of time for teaching versus depth of understanding?
9. Choose one "golden line" from this chapter (a sentence that really speaks to or resonates with you). Write this on a sentence strip and share it with others. Describe why you chose it.
10. What was the biggest "takeaway" from this chapter for you? What will you do or think about differently as a result?

Extending Your Learning With NSTA Resources

1. Read and discuss this article, which shows how elementary children connect newly learned material to their existing knowledge: Kang, N., and C. Howren. 2004. Teaching for conceptual understanding. *Science and Children* 41 (9): 29–32.
2. Read and discuss this article, which explains how to create and use an interactive word wall: Jackson, J., and P. Narvaez. 2013. Interactive word walls. *Science and Children* 51 (1): 42–49.
3. Read and discuss this article, which describes how thought and language are intricately related: Varelas, M., C. Pappas, A. Barry, and A. O'Neill. 2001. Examining

language to capture scientific understandings: The case of the water cycle. *Science and Children* 38 (7): 26–29.

4. Read and discuss this article, which describes the crosscutting concepts: Duschl, R. 2012. The second dimension: Crosscutting concepts. *Science and Children* 49 (6): 10–14.
5. Read and discuss this article about use of the words *theory* and *hypothesis*: McLaughlin, J. 2006. A gentle reminder that a hypothesis is never proven correct, nor is a theory ever proven true. *Journal of College Science Teaching* 36 (1): 60–62.
6. Read and discuss this article about how word choice affects students' understanding of the nature of science: Schwartz, R. 2007. What's in a word? How word choice can develop (mis)conceptions about the nature of science. *Science Scope* 31 (2): 42–47.
7. Read and discuss this NSTA Press book about building data literacy: Bowen, M., and A. Bartley. 2013. *The basics of data literacy: Helping your students (and you!) make sense of data*. Arlington, VA: NSTA Press.
8. Read and discuss Chapter 3 "Foundational Knowledge and Conceptual Change" in Michaels, S., A. Shouse, and H. Schweingruber. 2008. *Ready, set, SCIENCE!* Washington, DC: National Academies Press.
9. The authors' NSTA Press series *Everyday Science Mysteries* (Konicek-Moran) and *Uncovering Student Ideas in Science* (Keeley) contain a wealth of information on children's alternative conceptions and strategies for eliciting children's ideas. Read and discuss sections from these books. You can learn more about these books and download sample chapters at the NSTA Science Store: *www.nsta.org/store*
10. Watch the NSTA archived *NGSS* webinar on developing and using models: *http://learningcenter.nsta.org/products/symposia_seminars/NGSS/webseminar6.aspx*
11. View videos of authors Dick Konicek-Moran and Page Keeley discussing the importance of understanding children's ideas: *www.nsta.org/publications/press/interviews.aspx*

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

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Teaching FOR Conceptual Understanding IN Science

What do you get when you bring together two of NSTA's bestselling authors to ponder ways to deepen students' conceptual understanding of science? A fascinating combination of deep thinking about science teaching, field-tested strategies you can use in your classroom immediately, and personal vignettes all educators can relate to and apply themselves.

Teaching for Conceptual Understanding in Science is a collaboration between Richard Konicek-Moran, a researcher and professor who wrote the *Everyday Science Mysteries* series, and Page Keeley, a practitioner and teacher educator who writes the *Uncovering Student Ideas in Science* series. Written in an appealing, conversational style, this new book

- explores where science education has been and where it's going;
- emphasizes how knowing the history and nature of science can help you engage in teaching for conceptual understanding and conceptual change;
- stresses the importance of formative assessment as a pathway to conceptual change; and
- provides a bridge between research and practice.

This thought-provoking book can truly change the way you teach. Whether you read each chapter in sequence or preview topics covered by the vignettes, Konicek-Moran and Keeley will make you think—*really think*—about the major goal of science education in the 21st century: to help students understand science at the conceptual level so they can see its connections to other fields, other concepts, and their own lives.

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Powerful Practices Series

The POWER of Questioning

Guiding Student Investigations

Julie V. McGough and Lisa M. Nyberg

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National Science Teachers Association

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NSTA press
National Science Teachers Association
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Dedicated to all teachers who inspire children with minds full of wonder to seek answers to a lifetime of questions.

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Building a Questioning Environment

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Part 3: How Do I Implement the Power of Questioning?

Engaging in Purposeful Discussion

Color Coding

Throughout *The Power of Questioning*, the text, illustrations, and graphics are color-coded to indicate the components of the instructional model.

Questioning is printed in **red**.

Investigations are printed in **blue**.

Assessments are printed in **purple**.

When thoughtful **questioning** is combined with engaging **investigations**, amazing **assessments** are produced—just as when **red** and **blue** are combined, **purple** is produced.

We've also provided links and QR codes to the NSTA Extras page where you can view videos related to content throughout the book. Visit *www.nsta.org/publications/press/extras/questioning.aspx* to view all supplementary content.

Learn from yesterday, live for today, hope for tomorrow.

The important thing is not to stop questioning.

Albert Einstein

(*Relativity: The Special and the General Theory,* 1920)

Why Does Skill in Questioning Engage Students in Purposeful Standards-Based Learning?

Students need opportunities to develop science literacy through solving problems and explaining phenomena and observations (NRC 2000). They also need to see purpose for what they are learning as they engage in literacy practices. Children ask questions and make connections to what is being learned in the classroom every day—on the playground, at home, walking to and from class, and when listening to stories and presentations. Sharing these connections through academic discourse helps students formulate new ideas and reconstruct old ones by adding new information from others' experiences.

Academic subjects are often regulated by national and state standards such as the *NGSS* and the *Common Core State Standards* (*CCSS*). These standards may lead teachers to engage children in higher-level thinking than they otherwise would through questioning, investigations, and authentic performance assessments. The standards build a bridge to connect real-world problem solving to the application of academic knowledge and skills. Additionally, the standards may guide teachers to engage children in complex cognitive processes so students may produce multidimensional work products illustrating higher-level thinking.

For example, during a study of the structure and function of plants, Cienna remembered her experience of noticing the tiny root hairs growing on a carrot while harvesting plants in the garden (photo on opposite page). She applied the information from the experience when building a model plant, deepening her understanding of the concept of how plant roots work. (Visit *www.nsta.org/publications/press/extras/files/practices/questioning/video2.htm* or scan the QR code on p. 18 to see a video.) Table 1.1 (p. 10) illustrates the *CCSS* and *NGSS* relevant to Cienna's discovery.

Table 1.1. Standards-Based Learning: Structure and Function of Plants
Examples of standards used during the study of the structure and function of plants. DOK = Depth of Knowledge (see p. 22); ELA, English language arts.

National Standards	Standards-Based Learning
***NGSS*: Life Science** **LS1.A:** Structure and Function ***NGSS*: Engineering** **ETS1.2:** Developing and Using Models	***NGSS*** Children learn that plants have internal (xylem, phloem, veins) and external (roots, stems, leaves, flowers, fruits) parts that help them survive and grow by investigating (e.g., planting seeds, placing a carrot top in water) and observing real plants over time (e.g., garden experiences) (DOK Levels 1 and 2). Children develop models to describe phenomena (DOK Level 3).
***CCSS ELA*: Reading Informational Text** **RI.7:** Use illustrations and details in a text to describe and explain key ideas ***CCSS ELA*: Speaking and Listening** **SL.2:** Ask and answer questions about key details **SL.4:** Describe things with relevant details **CCR.4:** Present information, findings, and supporting evidence **SL.5:** Add visual displays to descriptions to clarify ideas	***CCSS ELA*** Children ask questions about the parts of the plant and how the parts work to help the plant grow. The children use informational text to explain the different internal and external plant parts. Students describe how plants work and present their information to others using the model plant as a visual display to clarify ideas.

What does a discussion reviewing the structure and function of plants with a model built by students sound like?

Scan the QR code or visit *www.nsta.org/publications/press/extras/files/practices/questioning/video1.htm* to listen to a discussion with different types of questions.

Connecting Questions and Learning: Structure and Function of Plants

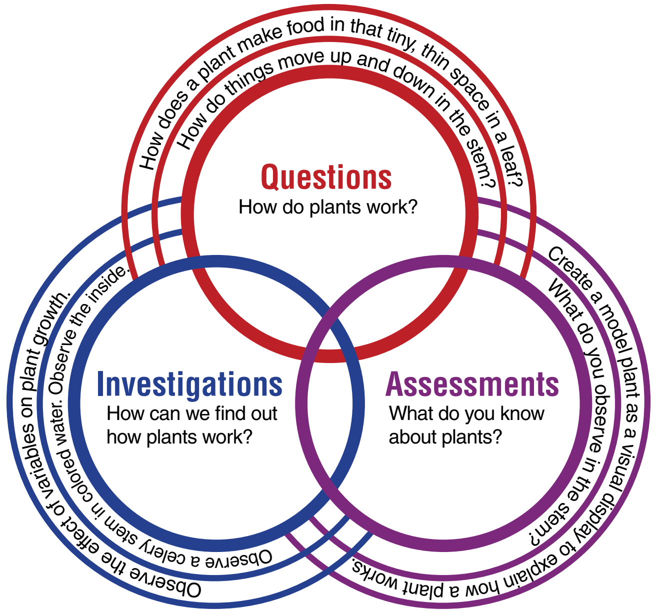
When exploring the concept of structure and function during a unit on plants, students make connections to their world by observing specific details of real seeds, roots, stems, and leaves at home, on the school campus, and in a school garden (McGough and Nyberg 2013b). Students conduct investigations such as examining and labeling the parts of a pumpkin in the fall, observing and comparing different kinds of seeds from the garden, observing a sunflower plant go to seed at the end of its life cycle, and planting seeds.

A variety of learning experiences involving plants give students context to engage in thinking and questioning throughout the unit of study (McGough and Nyberg 2013a). Reading informational text in addition to making firsthand observations stimulates even more questions. The teacher asks, "What questions do you have about plants and how they work?" This question causes students to reflect on what they have learned so far and then extend their thinking.

Using Unit Planning Guides

Student questions prompt further investigations, which advance the cycle of learning. As you design a unit, a planning guide can help you determine engaging questions, purposeful investigations, and authentic assessments to push the cycle forward. Students' extensive studies allow for crosscurricular connections. For example, after hands-on learning about plants, students might read informational text that describes and explains key ideas (English language arts standards) about how plants work (science content standards). Then, they could investigate how different variables affect plant growth (water, soil nutrients, and sunlight). Purposeful investigations help students build understanding of key concepts and might lead to an authentic performance task of building a model plant (science and engineering practices) to articulate how the structure of a plant helps a plant function (Figure 1.3).

Figure 1.3. Powerful Practices Model: Structure and Function of Plants
An example of the Powerful Practices model filled out during a unit on the structure and function of plants.



A comprehensive unit planning guide includes such crosscurricular possibilities (Figure 1.4, p. 14, illustrates a visual reference for crosscurricular connections) as well as content and academic vocabulary, resources, and differentiation strategies. An example of a complete unit planning guide for the unit on the structure and function of plants is shown in Figure 1.5 (pp. 15–17).

Figure 1.4. Brainstorming Crosscurricular Connections

Science: Investigate how seeds, roots, stems, and leaves work.

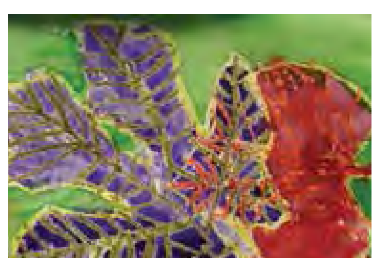
Technology: Produce and publish writing and collaborate with others through a classroom blog.

Engineering: Build a model plant to show how a plant works.

Math: Measure plants growing in the garden.

ELA: Record plant observations in a science journal including labeled drawings.

Social Science: Locate where foods are grown and transported to and from on the map.



Art: Observe leaf shapes and veins. Create a crayon resist of leaves.

Figure 1.5. Unit Planning Guide: Structure and Function of Plants

Unit Planning Guide

Core Idea/Topic: Structure and Function of Plants

Concepts: Plant parts, plant needs, photosynthesis

Questions to Drive the Inquiry

1. What do you know about plants?
2. How do plants work?

Student Questions

1. How does a plant make food in that tiny, thin space in the leaf?
2. How do things move up and down in the stem?
3. How does air go in and out?

Investigations

1. Observe how different variables affect plant growth (water, soil nutrients, sunlight).
2. Observe a celery stem in colored water.
3. Use straws to suck up water from a cup. Place a finger over the straw when it is in the water. Discuss.
4. Place a plastic bag over a leaf on a plant outside. Observe over time.

Timeline

Standards

NGSS

LS.A Structure and function of plants; LS.B Growth and development of organisms (plants); LS.C Organization for matter and energy flow in organisms (plants); LS.D Information processing; ETS1.2 Developing and using models

CCSS ELA

RI.1 Key ideas and details; RI.4, RI.5 Craft and structure; RI.7 Integration of knowledge and ideas; W.5, W.6 Production and distribution of writing; W.7, W.8 Research to build and present knowledge; SL.1, SL2, SL.3 Comprehension and collaboration; SL.4, SL.5, SL.6 Presentation of knowledge and ideas

Performance Assessment

1. Students will build a model plant using straws, tubes, lids, netting, bubble wrap, and other objects.
2. Students will present their model plant to the class and explain how a plant works.
3. Students will write a report or create a brochure that explains how plants make food, what plants are used for, and why plants are important.

Index

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

The POWER of Questioning

Guiding Student Investigations

This pedagogical picture book invites you to nurture the potential for learning that comes from children's irrepressible urges to ask questions. Part of NSTA's *Powerful Practices* series for elementary educators, *The Power of Questioning* offers you

- **a solid foundation in both theory and practice.** The book's three-part instructional model is grounded in questioning, investigation, and assessment. Both you and your students will learn how to question effectively, making investigations more engaging.
- **an unusual opportunity to see a model brought to life.** The authors provide vivid pictures as well as links to special videos and audio recordings. You can actually hear teachers and students engage in questioning and watch two easy-to-adapt examples (involving plants and life cycles) of the model in action. Then, you can implement the new strategies right away in your own classroom.
- **standards- and STEM-friendly benefits.** The book also illustrates how to integrate state standards, the *Next Generation Science Standards*, the *Common Core State Standards*, and STEM education practices.

The Power of Questioning is a fresh, lively source of strategies both you and your students will enjoy. The authors are veteran educators who know how busy and demanding today's K–6 classroom is. This easy-to-use volume is proof that sometimes a powerful tool comes in a small package.

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OKHEE LEE • EMILY MILLER • RITA JANUSZYK

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PREFACE

OKHEE LEE

The *Next Generation Science Standards* (NGSS Lead States 2013) are being implemented when critical changes in education are occurring throughout the nation. On one hand, student demographics across the country are changing rapidly and teachers have seen the steady increase of student diversity in the classroom, while achievement gaps in science and other key academic indicators among demographic subgroups have persisted. On the other hand, the *NGSS* and the *Common Core State Standards* (CCSS), in English language arts and mathematics are spreading. As these new standards are cognitively demanding, teachers must make instructional shifts to prepare all students to be college and career ready. Furthermore, as the standards are internationally benchmarked, the nation's students will be prepared for the global community.

The *NGSS* offer both opportunities and challenges for educators in enabling all students to meet the more rigorous and comprehensive standards set forth by the *NGSS*. The *NGSS* indicate performance expectations of students by blending science and engineering practices, crosscutting concepts, and disciplinary core ideas. Most science teachers are unaccustomed to teaching for three-dimensional learning and will be compelled to make adjustments in their instruction.

The *NGSS* have addressed issues of diversity and equity from the inception. The *NGSS* Diversity and Equity team takes the stance that the standards must be made accessible to all students, especially those who have traditionally been underserved in science classrooms, hence the title "All Standards, All Students." Through the two-year process of the *NGSS* development, the team completed four major charges: (1) bias reviews of the *NGSS*, (2) Appendix D on diversity and equity, (3) inclusion of the topic of diversity and equity across appendixes, and (4) seven case studies of diverse student groups.

Within the broader scope of the team's charges, this book focuses on the seven case studies written by the team members who are classroom teachers. The case studies are an attempt to pilot the vision presented in *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (hereafter referred to as the *Framework*; NRC 2012) and the *NGSS* with respect to diverse student groups across grade levels and science disciplines. These case studies illustrate how teachers blend the three dimensions of the *NGSS* with effective classroom strategies to ensure that the *NGSS* are accessible to all students. Furthermore, they provide practical and tangible routes toward effective science instruction with diverse student groups.

Each case study consists of four parts. First, it starts with a vignette of science instruction to illustrate learning opportunities through effective classroom strategies and connections to the *NGSS* and *CCSS ELA* and *CCSS Mathematics*. The vignette emphasizes what teachers *can do* to successfully engage students in meeting the *NGSS*. Second, it provides a brief summary of the research literature on effective classroom strategies for the student group highlighted in the case study. Third, it describes the context for the student group—demographics, science achievement, and educational policy. Finally, it ends with an *NGSS*-style foundation box for a user-friendly review of the *NGSS* and the *CCSS* that were taught in the vignette.

The vignettes in the seven case studies were modeled after those of *Ready, Set, Science! Putting Research to Work in K–8 Science Classrooms* (Michaels, Shouse, and Schweingruber 2008)—which is a companion to *Taking Science to School: Learning and Teaching Science in Grades K–8* (NRC 2007)—as a precursor to the *Framework*. Both sets of vignettes authenticate ideas about science education through classroom trials. However, the vignettes in this book differ in several ways: (1) they represent seven diverse demographic groups of students within the same volume; (2) they illustrate the blending of science and engineering practices, crosscutting concepts, and disciplinary core ideas; (3) they include research-based classroom strategies to improve access of diverse student groups to the NGSS; (4) they are extensive, ranging from two weeks of science instruction to an entire school year; and (5) they span K–12 grade levels and include all science disciplines.

While the book focuses on the seven case studies, we expand its scope by including seven additional chapters. The book begins with contributions by Stephen Pruitt (Chapter 1), Helen Quinn (Chapter 2), and Andrés Henríquez (Chapter 3). Then, we describe the team's charges (Chapter 4) and our conceptual framework to guide the readers in how to interpret and apply the case studies across classroom contexts (Chapter 5). The main body of the book includes the seven case studies (Chapters 6 through 12), to be followed by professional development considerations and a reflection guide for each case study. Next, we offer suggestions about how teachers can draw from case studies to inform their unit design by incorporating important shifts to support student learning (Chapter 13). Finally, Joe Krajcik, in collaboration with Emily Miller, introduces a teaching rubric that assists reflection on three-dimensional learning and focuses on equity (Chapter 14). By keeping a balance between the case studies and chapters, we maintain the integrity of the *NGSS* work on the case studies while further enhancing the team's work to make it more relevant and applicable to the broader education system.

The book makes significant contributions in several ways. First, the case studies in the book are an integral part of the development of the *NGSS*. Content standards across subject areas are written for all students, but the specific opportunities and demands that are extended to diverse student groups through rigorous standards have never been similarly addressed. Second, educational research tends to address diverse groups separately but not collectively as this book does. Third, the book benefits from the combination of teacher, expert, and "teacher-as-expert" voices. Teacher-practitioners offer invaluable insights into implementation of the *NGSS* with diverse student groups, adding authenticity to the claim of utility for science educators. Finally, the book provides the context for each student group in terms of demographics, science achievement, and educational policy.

This book is intended for K–12 science educators, science supervisors, leaders of teacher professional development, education researchers, and policy makers. The primary audience of the book is classroom teachers. We encourage them to make instructional shifts in implementing the *NGSS* with diverse student groups who have historically not met district and state goals in science. In addition, this book is intended for science supervisors and professional development providers to offer support systems for classroom teachers. Furthermore, this book serves as a guide for teachers, supervisors, or professional development providers to design action plans for the *NGSS* implementation with diverse student groups. Through this publication, the case studies may reach a broad audience and initiate dialog about how to enable all students to achieve the academic rigor of the *NGSS*.

We would like to acknowledge many individuals who contributed to this book. First of all, we appreciate those individuals who contributed to the case studies:

1. *Economically Disadvantaged Students:* Rita Januszyk wrote the case study. The vignette is based on the video of the teaching of Bethany Sjoberg, Highline Public Schools, Seattle, WA. The video came from Windschitl, M., J. Thompson, and M. Braaten (2008–2013). *Tools for ambitious science teaching.* National Science Foundation, Discovery Research K–12, *http://tools4teachingscience.org*. Joseph Krajcik and Cary Sneider, both *NGSS* writing team members, collaborated on the vignette.
2. *Students From Racial and Ethnic Groups:* Emily Miller wrote the case study. She worked with Susan Cohen, a middle school science teacher at Madison Metropolitan School District and planned the curriculum with Leith Nye, Great Lakes Bioenergy Resource Center, Wisconsin.
3. *Students With Disabilities:* Betsy O'Day, *NGSS* Diversity and Equity Team member, wrote the case study.
4. *English Language Learners:* Emily Miller wrote the case study. She planned the unit with Nick Balster, University of Wisconsin–Madison, and taught the unit with her team members Stacey Hodkiewicz and Kathy Huncosky, Madison Metropolitan School District, Wisconsin.

5. *Girls:* Emily Miller wrote the case study. The vignette is based on the teaching of Georgia Ibaña-Gomez, School District of Cambridge, Wisconsin, and curriculum planning with Cheryl Bauer Armstrong from the Earth Partnership for Schools at the University of Wisconsin–Madison. Cary Sneider, *NGSS* writing team member, collaborated on the vignette.
6. *Students in Alternative Education:* Bernadine Okoro, a member of the *NGSS* Diversity and Equity Team, wrote the case study in collaboration with Emily Miller.
7. *Gifted and Talented Students:* Rita Januszyk wrote the case study.

In addition to Betsy O'Day and Bernadine Okoro, we also would like to acknowledge Jennifer Gutierrez and Netosh Jones, two additional members of the *NGSS* Diversity and Equity Team.

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CHAPTER 8

STUDENTS WITH DISABILITIES AND THE *NEXT GENERATION SCIENCE STANDARDS*

Members of the *NGSS* Diversity and Equity Team

ABSTRACT

The percentage of students identified with disabilities in schools across the nation is currently around 13%. As a result of the Elementary and Secondary Education Act (ESEA), school districts are held accountable for the performance of students with disabilities on state assessments. Although students with disabilities are provided accommodations and modifications when assessed, as specified in their Individualized Education Plans (IEP), achievement gaps persist between their science proficiency and the science proficiency of students without disabilities. The vignette below highlights effective strategies for students with disabilities: (1) multiple means of representation, (2) multiple means of action and expression, and (3) multiple means of engagement. These strategies support all students' understanding of disciplinary core ideas, science and engineering practices, and crosscutting concepts as described by the *Next Generation Science Standards* (*NGSS*).

VIGNETTE: USING MODELS OF SPACE SYSTEMS TO DESCRIBE PATTERNS

While the vignette presents real classroom experiences of *NGSS* implementation with diverse student groups, some considerations should be kept in mind. First, for the purpose of illustration only, the vignette is focused on a limited number of performance expectations. It should not be viewed as showing all instruction necessary to prepare students to fully understand these performance expectations. Neither does it indicate that the performance expectations should be taught one at a time. Second, science instruction should take into account that student understanding builds over time and that some topics or ideas require extended revisiting through the course of a year. Performance expectations will be realized by using coherent connections among disciplinary core ideas, science and engineering practices, and crosscutting concepts within the *NGSS*. Finally, the vignette is intended to illustrate specific contexts. It is not meant to imply that students fit solely into one demographic subgroup, but rather it is intended to illustrate practical strategies to engage all students in the *NGSS*.

INTRODUCTION

There are five sixth-grade classes at Maple Grove, the only middle school in a small rural school district. Approximately 10% of the K–12 school population receives special education services. The school has about 480 students in grades 6–8. The district population consists of 1,320 students: 92.3% white, 3.6% African American, 2% Hispanic, 0.5% Asian, and 0.3% Native American; 34% are classified as low socioeconomic status.

The incidence rates of identified special education students in the district are highest in the categories of specific learning disabilities (2.4%) and other health impairments including ADD/ADHD (2.7%). In addition, 1.1% of students are in the category of "speech impaired," 1.4% "language impaired," 0.8% "intellectual disabilities," and 0.8% "autism."

There are special education students in each of the sixth-grade classes with Individualized Education Plans (IEPs) that specify the accommodations and modifications when participating in the regular education classroom. Mr. O. thinks about potential barriers that any of his students, including those with special needs, may have to the planned instruction. Then he adjusts instruction to overcome those barriers. Often, changing an approach to accommodate barriers makes instruction more effective for all students. The students with disabilities, along with their regular education peers, receive science instruction from the science teacher five days a week for 50 minutes each day. Most of the identified students receive instruction in reading/language arts and mathematics in a coteaching model. Some students receive additional pullout services in those content areas or in social skills.

In the lesson sequence in this vignette, Mr. O. uses multiple means of representations for Moon phases—Stellarium (planetarium software), Styrofoam balls, a lamp, golf balls, and foldables (three-dimensional interactive graphic representations developed by Zike). Mr. O. provides additional practice for students who may need it, such as placing cards with Moon phases in chronological order and then identifying each phase. He modifies assignments for students with intellectual disabilities as mandated by their IEPs. In addition, strategic grouping of students provides support for struggling students, including special education students. Throughout the vignette, classroom strategies that are effective for all students, particularly for students with disabilities according to the research literature, are highlighted in parentheses.

SPECIAL EDUCATION CONNECTIONS

Jeanette and Nicole have intellectual disabilities; they have a paraprofessional who accompanies them to selected regular education classrooms, providing instructional support. Nicole is identified with socio-emotional disability and receives special education services for both language arts and mathematics. Kevin is diagnosed with autism, exhibits difficulties in social skills, and is cognitively high functioning. Hillary and Brady have specific learning disabilities and receive special education services for both language arts and mathematics. Jeff is also identified with specific learning disabilities and receives services for language arts. His math skills are advanced for his grade level. All of these students are part of the diverse community of learners working toward three-dimensional scientific understanding of the Earth-Sun-Moon relationship, as described in this vignette.

Exploring the Earth-Sun-Moon Relationship

Mr. O. initiated the unit by asking students to open their notebooks, write the numbers 1–8 down the next blank page, and title the page "Relative Diameters?" On the interactive whiteboard, he projected a slide from a multimedia presentation *Two Astronomy Games* that showed nine images, each identified by a letter and a label (Morrow 2004). The images were the Sun, Earth, a space shuttle, the Moon, the solar system, Mars, a galaxy, and Jupiter. Students were asked to number the objects in order from smallest (number 1) to largest (number 8) and from nearest to the surface of the Earth to farthest from the surface of the Earth. He planned to have students come back to this page later. Kevin seemed pleased and announced, "I love to study space!"

With a standard-size playground ball in hand, Mr. O. asked the class to imagine the ball was Earth and he wrote down the class' consensus of the ball's dimensions that they had figured out in math class. Then he presented the class with a box of seven balls in a variety of sizes and listed their dimensions on the interactive whiteboard. He asked: "If Earth was the size of this playground ball, which of these balls would be the size of the Moon?" One student (from each table) came up and chose the ball they thought would be correct. Their choices varied from a softball to a small marble. Before going further, the class reviewed the term *diameter* and Mr. O. asked, "If you know that Earth's diameter is 12,756 kilometers and the Moon's diameter is 3,476 kilometers, with your table groups, come up with a method to see if the ball you chose is the right size for this size Earth [holding up the playground ball]" (practice: Using Mathematics and Computational Thinking) (CC: Scale, Proportion, and Quantity).

After some discussion time, students reported their calculations. One group noticed that there was a proportional relationship in the diameters of approximately 1:4, Earth to Moon. A student asked how they made that determination. Jeff responded, "If you estimate using 12,000 and 3,000, three goes into twelve four times." He showed on the interactive whiteboard how four circles of the Moon fit across the diameter of the Earth. Mr. O. said, "Now think of your ball as a representation of the Moon and decide if you think it is the correct size. What can you do to be sure? Decide on a process." He let them use the playground ball as needed (DCI: MS-ESS1.A Earth's Place in the Universe).

Each group reported their findings and methods for determining whether or not their choice would be correct. One group made lines on paper where the endpoint of their ball was and did the same for the playground ball. Using those measurements and the 1:4 ratio, they decided if their Moon was the correct size. Another group used string to measure the diameter of the balls and then determined whether or not it was correct. Still another group held their ball up against the playground ball and moved their ball four times while marking the playground ball with a finger to see if their ball was the correct size for the model of Earth.

The groups reported their findings. Kevin was agitated as he explained, "I told my group they were not right. The racquetball is the only one that is possible as the Moon, but they wouldn't believe me." Mr. O. asked Kevin to restate the rule for when his group disagrees. Kevin thought and said, "When my group disagrees, I listen and then tell them what I think."

Only those groups with the racquetball had the correct size for the playground ball. Two of the students from one of those tables came up and showed how far they thought the Moon would be from Earth using the playground ball and racquetball model. Several students disagreed with the distance shown by the students. Four students came to the front, one by one, and showed their ideas about the distance between Earth and the Moon. Then Mr. O. showed them the actual distance from Earth to the Moon and the circumference of Earth in kilometers. He asked them again to use the new evidence to determine how to figure out the distance in the model and to show it using string. Students were shocked at the distance the Moon was from Earth in this model. Their estimates had been much lower.

As the class finished presenting their arguments for the correct size balls for the Sun and Earth, students considered the relative size of the Sun and the distance of the Sun from Earth in the model. They used the evidence of the diameter of the Sun and its distance from Earth in the same way they determined the size and distance of the Moon from Earth. Some students were surprised at the size of the Sun and its distance from Earth in this model. Jeff decided that they could not fit the Sun in the room. He explained that it would take over 100 playground balls to approximate the Sun's diameter. Jeff was eager to share his mathematical skill at finding the answer: "I know the answer! It would take almost 12,000 playground balls lined up to show how far away the Sun would be in this model." Two students nonchalantly said, "That's a lot," and "The Sun is very far away from Earth" (CC: Scale, Proportion, and Quantity).

The students returned to their initial ideas on the "Relative Diameters" page in their notebooks, renumbered the objects, and recorded any ideas that had changed after making the model. After giving students time to write their responses, Mr. O. showed images of the items on the interactive whiteboard and led a discussion of the great distances between objects in the solar system in preparation for modeling the Moon's phases (DCI: MS-ESS1.B Earth's Place in the Universe).

For this lesson sequence, Mr. O. considered the makeup of the table groupings of students. He wanted the special education and other struggling students to have support while determining methods to check their choice of the Moon model, so he grouped students with that concern in mind. He used physical representations of Earth and the Moon and had students represent the distance physically, thereby assisting them in visualization and comprehension. *(The strategy of providing multiple means of representation was important to support understanding for his special education students, but it also benefited all of his students.)*

Exploring Moon Phases

Mr. O. showed how the Moon's and Earth's orbital planes are offset by 5 degrees in an effort to help students understand how light can illuminate the Moon when it is on the other side of Earth without being blocked by Earth's shadow. Throughout this instruction the special education students were strategically placed at tables in groups that would support their engagement in the content and activity.

Mr. O. downloaded an open-source planetarium program onto his whiteboard-connected computer as well as onto the 14 student computers he had in his classroom. On the first day of Moon phase instruction, each student received a one-page Moon calendar similar to one they took home. The students who had completed the calendar kept it out to compare their observations to the data collected using the software. Mr. O. launched the program on the interactive whiteboard, introduced the students to the software, and showed them how to change the date and set up the scale Moon so they could see the phases.

Recording began on the first Sunday on the calendar and ended on the last Saturday, resulting in five weeks worth of data to analyze (practice: Analyzing and Interpreting Data). Mr. O. modeled how to record the data on the whiteboard next to the interactive whiteboard. Students recorded the time and location of moonrise and moonset as well as the apparent shape of the Moon in the sky for each date. To make sure that students understood the process and were recording accurately, he walked through the room and checked student work throughout the lesson. Also during this modeling process, the students paid attention to the Sun-Moon relationship so they could see the light from the Sun traveling in a straight line to the Moon. The Moon was in the sky as the Sun was rising, and they focused on the Moon so that they could use the model for predictions. Mr. O. asked, "Does anyone know where the Sun is right now?" Brady responded, "It's more to the east and still rising." Using the time and date function in the program, he advanced the time to show the sunrise and said, "Look at the Sun and Moon. What pattern do you notice about the light on the Moon in relation to the Sun?" (CC: Patterns). Hillary answered, "It is going from the Sun to the Moon." Mr. O. responded, "Hmm. The light travels in a straight path from the Sun to the Moon. You have already learned that light travels in a straight line. Can we use that information to predict the position of the Sun even if we can't see it? Let's try as we continue."

After a few days' worth of data were collected, Mr. O. asked students to predict the time and direction for moonrise and moonset and brought their attention to the patterns in the data. He asked, "What time do you think the Moon will set on this day? The last time was 12:09." Mark said, "I think 12:59." Mr. O. advanced the time until the Moon set—at 13:08. Jeff called out, "So it is setting about an hour later each time." A student said, "So let's see if that pattern continues the whole month." Once the students had a foundation for data collection (about 8–10 days), they went to the computers in partners so they could work more independently to complete the data collection on the calendar.

Mr. O. wanted some control over the assignment of partners to provide support for students who needed it and to challenge more advanced students, so he predetermined the partners and assigned them before sending them to the computers. Jeanette and Nicole worked with their paraprofessional. As a modification to recording the data, they were given a calendar with a set of Moon phase images. As they worked with the paraprofessional, Jeanette said, "When do we write the answer?" Nicole answered, "You have to wait and look at Stellarium and glue the picture." The paraprofessional redirected Nicole and made sure that the directions were understood: Match the image to the one on Stellarium and glue it on the calendar for each day. They did not record the moonrise and moonset times. Hillary, Jeff, and Brady were each paired with a partner whose academic abilities were a little higher than their own, allowing them to receive some support from the partner. Kevin was paired with someone at the same ability level who would be patient with his unique social skills. Kevin enthusiastically stated, "I love science and I love to learn about space."

While students worked at the computers to complete the calendar, Mr. O. took aside small groups of students to do an activity in which they modeled Moon phases using Styrofoam balls, their heads, and a lamp with a bare bulb. Students stood in a circle around the lamp representing the Sun, holding a Styrofoam ball on a stick representing the Moon. They held the ball at arm's length and rotated their bodies using their heads as a representation of Earth so they could see the Earth view of the Moon in all its phases in the lit portion of the ball. The students went through the phases, naming each one and making sure that all students could see the lit portion on the Styrofoam balls for each phase.

Jeanette kept turning the wrong way as she looked at the student across from her. "Is this the way?" she asked, as Mr. O. gently helped direct her turn. Nicole was focused on the computer groups, so Mr. O. directed Nicole to look at the Styrofoam ball and the changing shadow. "What? I don't see the shadow," she said. Mr. O. pointed out the curve of light on the Moon. "I see it!" Nicole said.

Small groups allowed Mr. O to make sure that all students were able to accurately illustrate the phases in the model, giving him the opportunity to physically move them into position as necessary. In addition, he kept students from the first group who he felt might need more time with the model in the second group for more practice if needed.

The students collaborated to explain how the model of the Moon phases illustrated changes in the apparent shape of the Moon. They discussed limitations of the models—the things that a model is unable to show accurately. The students identified the relative sizes of the Sun, Earth, and Moon as well as the relative distances between each as being inaccurate in this model (practice: Developing and Using Models).

To finish the class period, all students were at the computers working with Stellarium and their calendars. Mr. O. walked around the room assisting students with their data collection. Jeanette called Mr. O. over and quietly said, "I lost the Moon and can't find it." He showed her how to search for it using the "find" function. Many of the students had changed the dates, so he stopped the class to note, "Many of you have found that this program shows future dates." To reinforce the language Mr. O. had used on many occasions throughout the unit, he asked, "What does that tell us about the planets and the Moon? They all move …" and students responded, "… in predictable patterns."

Over the next two days while students continued working on their calendar with Stellarium, Mr. O. again pulled small groups of students to use another model showing Moon phases (practice: Developing and Using Models). This one used golf balls that were painted black on half of the sphere, leaving the other half showing the side of the Moon lit by the Sun (Young and Guy 2008). The golf balls were drilled and mounted on tees so they would stand up on a surface. Mr. O. had two sets—one set up on a table that showed the Moon in orbit around the Earth in eight phase positions as the "space view" model (Figure 8.1), and the other with the model Moons set on eight chairs circled in the eight phase positions to show the "Earth view" model

FIGURE 8.1.

SPACE VIEW MODEL

First, students were shown the space view model and asked what they noticed about the Moons. Mr. O. wanted them to notice that the white sides of all the balls (showing light) faced the same direction. He asked them to identify the direction of the Sun. Nicole was looking toward the window, and Mr. O. asked her, "Nicole, where is the Sun in our model here in the classroom?" Nicole looked around and responded, "Over here, I think, because that's where the lit up sides are facing."

Then Mr. O. drew the students' attention to the model on the chairs, the Earth view model. All the balls in this model faced the same direction as those in the space view model. Students again identified the direction of the Sun and noted that the position of the Moons in both models was the same (DCI. MS-ESS1.A Earth's Place in the Universe). One at a time, students physically got into the center of the circle of chairs and viewed the phases at eye level (Figure 8.2, p. 90), which simulated the Earth view of each phase. (*Providing multiple means of action and expression is one of three principles of Universal Design for Learning.*)

FIGURE 8.2.

THE EARTH VIEW MODEL

Each of the students with Individualized Education Plans (IEPs) was put in a different small group, with the exception of Jeanette and Nicole, who were in the same small group. Their turn inside the circle was last, giving them the opportunity to observe, listen, and practice while verbalizing the phases and location of the Sun within the system. This activity made the diagram, often found in books and worksheets showing both views on the same diagram, less confusing to the students.

Although most students were not finished with the calendar, Mr. O. brought all students together the next day to create a foldable showing the Earth view of the Moon phases similar to diagrams found in books. Students created their Moon phases using eight black circles and four white circles, cutting the white circles to make two crescent Moons, two gibbous Moons, and two quarter Moons. The white circle pieces were placed on the black circles to create the phases, and later glued on the foldable. Jeanette was unsure of the placement of the pieces. "Where does this one go?" Jeanette asked referring to the gibbous Moons, which were incorrectly placed. "Look at mine. I'm right," said Nicole who also had confused the two phases. As he walked around the room checking student work, Mr. O. gently pointed out the lit side of the Moon and asked which phase that represented. Inside the foldable, students drew a large circle to represent the Moon. (*Providing multiple means of representation is one of the three principles of Universal Design for Learning.*)

They partnered to read *The Moon* by Seymour Simon (2003). Students used the information in the book to label the Moon phases on their foldable, write about the Moon's surface, and record any new questions that arose from their reading. Kevin asked, "When is the next solar and lunar eclipse?" Jeanette questioned, "What samples were brought back from the Moon?" And Nicole wanted to know, "Where did Americans land on the Moon?"

To support their reading of the text, Hillary, Brady, and Jeff were given the option of being paired with students who had more advanced reading skills or using Mr. O.'s recordings made on handheld computers. Jeanette and Nicole had the support of their paraprofessional in reading and obtaining information from the text. Mr. O. asked Kevin, "What would you prefer?" He answered, "Oh, I think this time I want to read by myself because I love space and want to find out more about the Moon." As students finished their reading and writing, they went back to finish their calendars using the software.

Students finished the calendar at different rates. When finished, they checked their work against the calendar that Mr. O. had completed. Since several pairs finished at the same time, he grouped the pairs to discuss the patterns they noticed in their calendars. He gave them a list of questions to guide their discussion and asked them to conference with him when they were finished. (*Providing multiple means of engagement is one of the three principles of Universal Design for Learning.*) He expected all students to observe that the lit segment of the Moon's face increased, decreased, and increased again relative to the part in shadow. He also expected students to notice that the lit side of the Moon was on the left after the full Moon phase and on the right after the new Moon phase, as viewed from Earth. Students who finished with all tasks were allowed to use text materials and internet resources to research answers to the questions they developed when reading *The Moon*, while the rest of the students completed their calendars.

Assessing Student Learning

Throughout the lesson sequence, Mr. O. continually assessed students' progression through observations and conferences. If he noticed students needed more experience with Moon phases, he provided them with additional activities such as videos and Moon phase cards. In one formal assessment of understanding, Mr. O. paired students together so that one was assigned to be the Earth and the other the Moon. He designated one wall of the classroom as the Sun and then asked the Moons to show different phases. The students switched roles so that Mr. O. could assess everyone. He also used this model to demonstrate the Moon's coincident rotation and revolution. In another formal assessment, he asked students to draw a model on whiteboards showing the relationship of the Earth, Moon, and Sun in full Moon phase.

NGSS CONNECTIONS

NGSS require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. This presents both challenges and opportunities to special education students, since a broad range of disabilities impacts their science learning. This vignette highlights examples of strategies that support all students while engaging in science practices and in rigorous content. The lessons give students varied exposure to the core ideas in space science, helping to prepare all students to demonstrate mastery of the three components described in the *NGSS* performance expectation. See Figure 8.3 (p. 95) for the comprehensive list of *NGSS* and *CCSS* from the vignette.

Performance Expectations

MS-ESS1-1 Earth's Place in the Universe
Develop and use a model of the Earth-Sun-Moon system to predict and describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.
MS-ESS1-3 Earth's Place in the Universe
Analyze and interpret data to determine scale properties of objects in the solar system.

Disciplinary Core Ideas

ESS1.A The Universe and Its Stars
Patterns of the apparent motion of the Sun, the Moon, and stars in the sky can be observed, described, predicted, and explained with models.
ESS1.B Earth and the Solar System
The solar system consists of the Sun and a collection of objects, including planets, their Moons, and asteroids that are held in orbit around the Sun by its gravitational pull on them.

Science and Engineering Practices

Developing and Using Models
Develop and use a model to describe phenomena.
Analyzing and Interpreting Data
Analyze and interpret data to determine similarities and differences in findings.

Students were engaged in a number of science practices with a focus on Developing and Using Models and Analyzing and Interpreting Data. Space science lends itself well to the use of models to describe patterns in phenomena and to construct explanations based on evidence. With guidance from their teacher, students used the ratios of the diameters of Earth and its Moon to construct a class model of the relative sizes of the two objects. Using distance and Earth's diameter or circumference ratios, they also constructed a distance model of those objects. In addition, the relative size of the Sun and the relative distance from Earth in this model was calculated and described, although not constructed (due to the constraints of the room and location). Throughout the vignette, a variety of models were used to help students identify patterns in the relative positions of the Earth, Moon, and Sun, and to explain Moon phases.

Crosscutting Concepts

Patterns
Patterns can be used to identify cause-and-effect relationships.
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.

Students made predictions about the data collected and recorded them on the calendar, using the lens of the crosscutting concept of Patterns. When analyzing and interpreting the data, they identified the patterns in the Earth-Sun-Moon relationship. The pattern made by the lit portion of the Moon was observed and recorded. In addition, students considered the crosscutting concept of Scale, Proportion, and Quantity as they constructed models of relative sizes and distance of the Sun and planets.

CCSS CONNECTIONS TO ENGLISH LANGUAGE ARTS AND MATHEMATICS

Students used the text in *The Moon* (Simon 2003) to label each phase of the Moon and summarize information about the surface of the Moon in their graphic organizer foldable. This reading and writing connects to the *CCSS ELA*:

- **RST.6-8.1** *Cite specific textual evidence to support analysis of science and technical texts.*
- **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.*

When comparing sizes and distances, students were challenged to find ways of comparing numbers, applying the *CCSS Mathematics* MP.1. In addition, students used rounding and estimation to calculate the quotients in the ratios, both skills developed in earlier grades and used again in fifth grade, standard 4.OA. Throughout the unit, students reasoned quantitatively as they compared the sizes of the Earth and Moon, standard MP.2. As students made conclusions about which ball was the Moon, they argued for their selection and agreed or disagreed with each other using their calculation, standard MP.3:

- **6.RP.A.1** *Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.*
- **MP.1** *Make sense of problems and persevere in solving them.*
- **MP.2** *Reason abstractly and quantitatively.*
- **MP.3** *Construct viable arguments and critique the reasoning of others.*

EFFECTIVE STRATEGIES FROM RESEARCH LITERATURE

Students with disabilities have IEPs, specific to the individuals, that mandate the accommodations and modifications that teachers must provide to support their learning in the regular education classroom. By definition, accommodations allow students to overcome or work around their disabilities with the same performance expectations of their peers, whereas modifications generally change the curriculum or performance expectations for a specific student (National Dissemination Center for Children with Disabilities 2010). Special education teachers can be consulted to provide guidance for making accommodations and modifications to help students with IEPs succeed with the *NGSS*.

Two approaches of providing accommodations and modifications are widely used by general education teachers in their classrooms. *Differentiated instruction* is a model in which teachers plan flexible approaches to instruction in the following areas: content, process, product, affect, and learning environment (Institutes on Academic Diversity 2009–2012). This vignette highlights Universal Design for Learning as a framework with a set of principles for curriculum development that provides equal access to all learners in the classroom (CAST 2012). The framework supplies a set of guidelines for teachers to use in curriculum planning that is organized around three principles: (1) to provide multiple means of representation, (2) to present multiple means of action and expression, and (3) to encourage multiple means of engagement. Teachers identify barriers that their students may have to learning and then use the framework to provide flexible approaches of instruction. While both differentiated instruction and Universal Design for Learning benefit students with disabilities, they also benefit all students.

FIGURE 8.3.

NGSS AND *CCSS* FROM VIGNETTE

MS-ESS1 Earth's Place in the Universe		
Students who demonstrate understanding can: **MS-ESS1-1.** Develop and use a model of the Earth-Sun-Moon system to predict and describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons. **MS-ESS1-3.** Analyze and interpret data to determine scale properties of objects in the solar system.		
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 6–8 builds on K–5 and progresses to developing, using, and revising models to support explanations, describe, test, and predict more abstract phenomena and design systems. • Develop use a model to describe phenomena. **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 and interpret data to determine similarities and differences in findings.	**ESS1.A: The Universe and Its Stars** • Patterns of the apparent motion of the Sun, the Moon, and stars in the sky can be observed, described, predicted, and explained with models. **ESS1.B: Earth and the Solar System** • The solar system consists of the Sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the Sun by its gravitational pull on them.	**Patterns** • Patterns can be used to identify cause-and-effect relationships. **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.

***CCSS* Connections for English Language Arts and Mathematics**

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts.

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.

6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.

MP.1 Make sense of problems and persevere in solving them.

MP.2 Reason abstractly and quantitatively.

MP.3 Construct viable arguments and critique the reasoning of others.

CONTEXT

DEMOGRAPHICS

The number of children and youth age 3–21 receiving special education services under the Individuals with Disabilities Education Act (IDEA) rose from 4.1 million in 1980 (10% of student enrollment) to 6.7 million in 2005 (14% of student enrollment) (National Center for Education Statistics 2011). By 2009, that number had decreased to 6.5 million (13% of student enrollment). Special education services under IDEA are provided for eligible children and youth who are identified by a team of professionals as having a disability that adversely affects academic performance.

Students with disabilities are also protected under Section 504 of the Rehabilitation Act of 1973, which covers all persons with a disability from discrimination in educational settings based solely on their disability. Section 504 requires a documented plan in which a school provides reasonable accommodations, modifications, supports, and auxiliary aides to enable students to participate in the general curriculum, although it does not require students to have an IEP. Since the implementation of Public Law 94-142 enacted in 1975, there has been concern about disproportionate representation of racial and ethnic minorities, economically disadvantaged students, and English language learners in special education programs (Donovan 2002; U.S. Commission on Civil Rights 2009). While there continues to be a disproportionate number (both overrepresentation and underrepresentation) of different populations of students identified in special education within general and specific disability categories, determining the factors that affect this inequality is difficult and complex.

SCIENCE ACHIEVEMENT

On the National Assessment of Educational Progress (NAEP) in science, the gap in grade 12 scores between students with disabilities and students with no disabilities has persisted at 38 points in 1996, 39 points in 2000, and 37 points in 2005. The grade 8 gap has continually decreased from 38 points in 1996, to 34 points in 2000, and to 32 points in 2005. The grade 4 gap increased from 24 points in 1996 to 29 points in 2000 before it finally decreased to 20 points in 2005. The results indicate two important points. First, while achievement gaps persisted across the three grade levels, patterns of increase or decrease were inconsistent at each grade level. Second, achievement gaps were wider as students advanced to higher grade levels.

In 2009, the NAEP science achievement gaps between students with disabilities (including those with 504 plans) and students with no disabilities were 32 points at grade 12, 30 points at grade 8, and 24 points at grade 4. This confirms that achievement gaps were wider as students advanced to higher grade levels, consistent with results in 1996, 2000, and 2005 described above.

The NAEP did not allow accommodations for students with disabilities prior to 1996. In 1996, some schools were allowed to use accommodations for students with disabilities while others were not allowed to assess the impact on NAEP results. In a continuing effort to be more inclusive, guidelines were developed that specified that students with disabilities should be included in the NAEP assessment. Despite attempts to standardize the inclusion process, exclusion rates vary across states (Stancavage, Makris, and Rice 2007).

Thus, all students with disabilities are not included in the NAEP science assessment, making it difficult to identify accurate achievement gaps between students with disabilities and their peers. In addition, the data are not disaggregated according to disability category, further complicating the process to identify spe cific achievement gaps. The National Assessment Governing Board recommended that NAEP should report separately on students with IEPs and those with 504 plans and should count only students with IEPs as students with disabilities. Prior to 2009, NAEP's "students with disabilities" category included both students with IEPs and students with 504 plans. In 2009, although students with 504 plans received accommodations according to their plans, their scores were reported in the category of students without disabilities.

EDUCATION POLICY

Enacted in 1975, Public Law 94-142, Education for All Handicapped Children Act, mandated the provision of a free and appropriate public school education in the least restrictive environment for children and youth ages 3–21 with disabilities. Public schools were required to develop an IEP with parental input that would be as close as possible to a nonhandicapped student's educational experience. The IEP specifies the types and frequencies of services to be provided to the student, including speech-language; psychological, physical and occupational therapy; and counseling services. It specifies the accommodations and modifications that are to be provided for the student in curriculum, instruction, and assessment. The IEP also described the student's present levels of academic performance and the impact of disabilities on performance.

Students with disabilities are also protected under Section 504 of the Rehabilitation Act of 1973. While special education services under IDEA [IDEA is described in more detail in the following paragraph] are provided for eligible children and youth who are identified by a team of professionals as having a disability that adversely affects academic performance, Section 504 covers all persons with a disability from discrimination in educational settings based solely on their disability. Section 504 does not require an IEP, but does require a documented plan in which the school provides reasonable accommodations, modifications, supports, and auxiliary aides to enable the student to participate within the general curriculum.

In 1990, Public Law 94-142 was revised and renamed Individuals with Disabilities Education Act (IDEA). The most recent revision and reauthorization was completed in 2004 with implementation in 2006. One notable change is the requirement that state-adopted criteria to identify students who have Specific Learning Disabilities (SLD) must not require a severe discrepancy between intellectual ability and achievement; must permit the use of a process based on the child's response to scientific, research-based intervention; and may permit the use of other alternative research-based procedures.

SLD, as a category, has the largest number of identified students and is defined by IDEA in the following way:

> *The term "specific learning disability" means a disorder in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, which disorder may manifest itself in the imperfect ability to listen, think, speak, read, write, spell, or do mathematical calculations … Such term includes such conditions as perceptual disabilities, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia … Such term does not include a learning problem that is primarily the result of visual, hearing, or motor disabilities, of mental retardation, of emotional disturbance, or of environmental, cultural, or economic disadvantage.* (TITLE I/A/602/30)

Under Elementary and Secondary Education Act regulations (ESEA 1965), students with disabilities are monitored for Adequate Yearly Progress (AYP) in the content areas of language arts and mathematics, with increased accountability expected as special education services continue (ESEA Title 1, Part A, Subpart 1. Sect 1111.b.2.C.V.II.cc.). Data on students' science progress are also collected and reported once at the elementary school level, middle school level, and high school level. In 2007, final regulations under ESEA and IDEA were released to allow more flexibility to states in measuring the achievement of students with disabilities (34 C.F.R. Part 200; U.S. Department of Education 2007).

The U.S. Office of Special Education created the IDEA Partnership to promote collaboration among the many national and state agencies and stakeholders dedicated to improving outcomes for students with disabilities. In response to the growing concern about increasing numbers of students identified with learning disabilities, there has been a call for identifying students at risk and implementing scientific, research-based intervention. The response to intervention (RTI) model is an effort to improve early intervention for students while improving learning outcomes and reducing the number of students identified as learning disabled.

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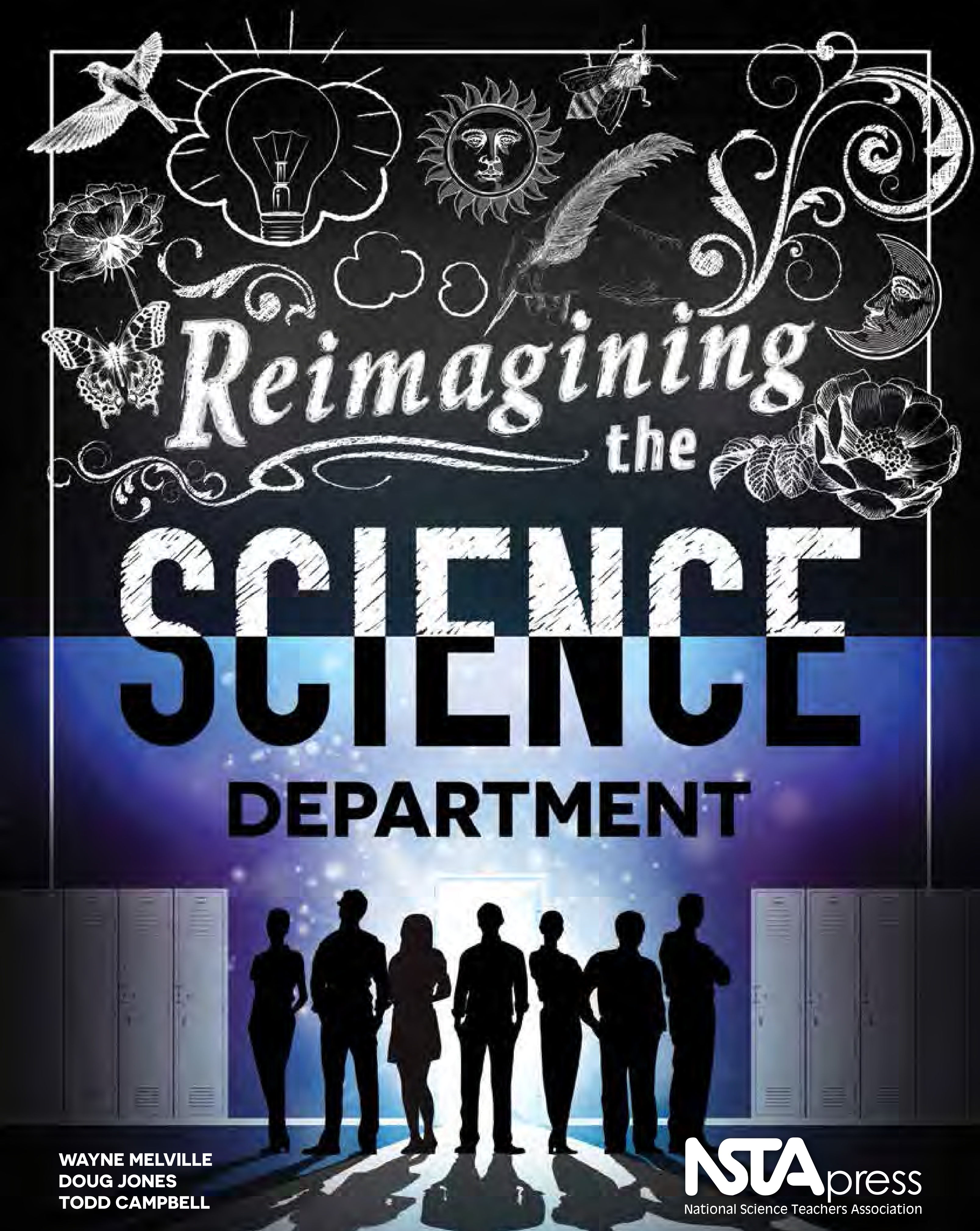
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FOREWORD

Why would anyone want to write a book about something as universal as the secondary science department? Science departments are a common feature in secondary schools, and everybody knows their purpose—right? Most typically seen as convenient administrative units within the school, science departments have also been described as the engine room of the school, the place where the hard work of teaching and learning science occurs. More ominously, for school administrators they can also appear completely impervious to the most carefully laid plans for school improvement and reform. Put simply, the ubiquity of science departments means that they are often hidden in plain sight.

Even within the research literature, serious investigations into departments are relatively recent phenomena. In her seminal 1994 work, Leslie Siskin defined four aspects of subject departments that she believed were crucial to understanding their importance: (1) Departments are administrative units formed along their strong disciplinary boundaries; (2) they are the primary places for teachers' social interaction; (3) they have considerable power over what and how teachers teach; and (4) they judge what is considered acceptable in terms of teaching and learning for the discipline (Siskin 1994). These aspects have guided our work with departments, as both chairs or researchers, over a number of years.

However, two things have become obvious to us in undertaking our work. The first is that the functions—and nuances—of departments are still not well understood in the research literature, and even that limited understanding has made only a slow passage into schools. The second is that the critical role of the chair remains an area that is both understudied and undervalued. This situation is concerning, particularly when it is known that chairs are the linchpin between the principles and assumptions supporting proactive reforms and their successful implementation. The United Kingdom's Teacher Training Agency (TTA) phrases it this way:

> *A subject leader has responsibility for securing high standards of teaching and learning in their subject as well as playing a major role in the development of school policy and practice. Throughout their work, a subject leader ensures that practices improve the quality of education provided, meet the needs and aspirations of all pupils, and raise standards of achievement in the school. (TTA 1998, p. 4)*

Science chairs are generally more experienced teachers with a solid grasp of both science content and pedagogy, and as middle managers they are in a unique position to influence the teaching and learning of both students and the teachers in their department. Yes, chairs have a responsibility to be good managers of the administrative side of the departments' operation. More importantly, they have the responsibility to be instructional leaders in their departments and to so help enact reforms to science education such as the *Next Generation Science Standards* (*NGSS*). However, if one looks at the history of reforms in science education, one sees a series of initiatives that looked good on paper but that stayed on the paper. Reformers often bemoan the inertia of teachers but continue to concentrate on the *what* of reform rather than the *how* of reform. The result is that increasingly cynical teachers see that the more change is called for, the more things stay the same. Clearly, such a situation does not benefit anyone, least of all the students in our classrooms. And make no mistake, students are voting with their feet and walking out of the discipline that we love. As Tytler (2007) points out, there is crisis in science education, characterized by secondary students developing increasingly negative attitudes toward science, a reduced participation in postcompulsory science education (especially in physics and chemistry), shortages of science-based workers, and a shortage of qualified science teachers.

This might all sound rather discouraging, but it also establishes the rationale for our work here. We firmly believe in the professionalism of science teachers, and as current, or past, chairs and science teachers, we understand and respect the pressures that act on both teachers and chairs. The purpose of this book is to assist science chairs, teachers, and administrators in beginning the task of reimagining the science department as a place where teachers are encouraged to question both their beliefs about science and the teaching and assessment strategies that develop in response to those beliefs. Only when teachers have the freedom and capacity to question their beliefs and develop their teaching and learning can real improvements in the teaching of the practices of science be sustained. This belief holds regardless of the school being urban, suburban, rural, public, or private. Between the three of us authors, we have taught in urban and rural independent schools in Australia, suburban public schools in Canada, and rural and urban Midwest schools—sometimes as the sole science teacher in the school. The writers of the vignettes, and our colleagues who have critiqued the earlier drafts, come from urban and rural areas in Ontario, New England, Georgia, and Texas. Different places and different teaching contexts, but for everyone who has contributed, the underlying departmental issues at the core of the work we are suggesting are the same.

The three-part structure of the book is designed to provide the reader with a firm foundation on which to base their actions. The first section, Chapters 1 and 2, places the science department in the context of its historical development, the relationship between the department and traditional science teaching, and the important (although under-recognized) role of the department in teacher professional learning. Most of us hold closely to an academic tradition of science education, and we need to recognize this before we can challenge it and its continuing impact on our teaching. The second section, Chapter 3, draws on the leadership and professional learning literature to consider the roles and responsibilities of science chairs in becoming instructional leaders. This section elaborates on many of the remarks in the National Science Teachers Association's position statements on leadership and professional development. We need to know the difficulties we will face if we are to move from recognizing, to challenging, to reforming our teaching and learning. To be prepared to reform means giving teachers good reasons to change. The pressure for reforms is not going to stop, so we need to be clear about the forces that drive that pressure and be proactive in dealing with them. The third section, Chapters 4 and 5, provides advice backed by research and experience on how to initiate reforms within the department and work with administrators to sustain and grow those changes over time. In this section we look at how chairs can make a start developing the credibility that is needed to influence the perceptions that departments have toward reforms, before finishing with the need to develop strong trusting relationships with school administrators in support of the work of the chair.

In our writing, we have constantly sought to avoid creating an "academic" book in the negative sense of two covers, pretentious prose, and wall-to-wall references. Such an approach does not reflect the day-to-day reality of departmental life. Conversely, where scholarly references add weight to the argument that we are making, we thought it appropriate that they be included. Theory and practice should not be seen as being diametrically opposed, they should inform and direct each other to improve the quality of teaching and learning. Our students deserve nothing less.

In each chapter we have included vignettes written by our colleagues that highlight the particular points made in the text; the issues that are faced are universal, and it is always nice to know you are not alone. We have also included questions to ask of yourself as a science teacher and as a chair. Such questions are important because to challenge the assumptions that underpin one's teaching, and then begin to really shift one's teaching and learning to a position that more closely resembles the ideals in reform documents such as the *NGSS*, is an intensely personal journey. Please feel free to rephrase the questions and use them in your own department as you see fit. As part of that journey, we would also like to invite you to send us anecdotes of your own trials, tribulations, growth, and successes connected to any of the chapters. If there is any way in which we can help you in your work, please don't hesitate to contact us.

Regards,
Wayne Melville, Doug Jones, and Todd Campbell
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ROLES AND RESPONSIBILITIES

The science department has existed in its current form for approximately 100 years. Over that time, the department has reflected the changing nature of the relationship between society and science. As science has acquired for itself greater prestige and power, so too has the science department become more entrenched at (or near) the top of the subject hierarchy found in so many secondary schools. This position has been reinforced by the close connections between university science faculties and departments and between disciplinary science and the academic script of science teaching. There is a tradition among science teachers as to what "good" science teaching looks like, and given how heavily teachers are socialized into this tradition, it is extremely difficult for an individual to challenge it alone. If, however, we believe that departments are places in which science teachers can begin to understand and challenge why they teach the way they do, and the imperatives for change, then we must also understand the roles and responsibilities of the person charged with the administrative management and instructional leadership of the department: the chair.

In this chapter, we start by considering how the role and responsibilities of the chair have evolved over the past 170 years. Following this history lesson, we will move on to consider the work of Jeremy Peacock who, working from the literature on science chairs, has highlighted four important leadership capabilities for contemporary science chairs looking to enact instructional leadership practices in their department. Those capabilities are then brought together with leadership theory to explore the relationship between departmental and instructional leadership. Establishing the links is not the same as providing a checklist that says "do these things and all will be well." It is a guide for understanding the nuances of leadership within the department. The hard work, as always, is to put the guide to the test in the day-to-day life of the department. Next, we will ponder the implications of the dominant current department structures on the leadership of the chair, before moving on to consider how chairs position themselves between the work of the department and the (often contradictory) requirements of districts and legislators. Finally, we will turn our attention to getting started on the road to reimagining the department.

The Chair: A Short History

The position of the chair has never been clearly defined, despite its key role in shaping instructional leadership within the department. The role has been seen at times as simply administrative: making sure that school policies are enacted and adhered to; at other times the chair has been tasked with ensuring that the examination requirements of the universities are met; and at still other times chairs have been given the responsibility for improving teaching and learning. Increasingly, however, all of these roles are being simultaneously delegated to the chair. One thing that has remained constant, however, is that the position has always been somewhat ambiguous, with little agreement on the functions or selection criteria. The more things change, the more they stay the same—since at least the 1840s.

Early Days: 1840s–1905

In the 1840s the early science educator Richard Dawes believed that the primary role of the teacher was to make "children observant and reflective; to make them think and reason about the objects about them … to instruct them in the school of surrounding nature, and to bring their minds to bear on the every-day work of life" (Layton 1973, p. 42). To achieve this, Dawes instructed the teachers in his parish schools in both content and how his curriculum was to be implemented. Dawes had little time for discussions into differentiated curriculum for different social classes. For him, teaching was a matter for which "the real difficulty of the question is not with the people, or the classes to be educated … but in getting it out of the hands of talking men and into those of the practical and working ones" (cited in Layton 1973, p. 48). The professionalization of science was to change this perception of the learning required by science teachers.

The establishment of science subjects that were closely aligned with the university disciplines had a profound effect on teaching and learning. For example, science (in the form of systematic botany) was established as a subject at the Rugby School in the 1850s and was taught as a "pure" science. Science was seen as a commonsense activity that required the learning of specific content and the laboratory skills needed to enter university science. As such, there was little effort to develop the pedagogical skill of the teachers. The role of the science chair was principally administrative, ensuring that the university-imposed standards were met. As we have seen, Michael Faraday spoke against the manner in which science was being taught, arguing that the result of an abstract scientific education was that even the supposedly well-educated were, in science, "ignorant of their ignorance" (Public Schools Commission 1864, p. 381).

Establishing Departments: 1905–1950s

From Kilpatrick's usage of the term *department* in 1905 until the middle of the 20th century, two important forces acted to shift the role of the chair away from the administrative focus of the early period. First, in the United States there was a significant growth of secondary enrollments driven by a number of factors: major demographic changes with large increases in immigration, the increasing urbanization of the population, and major changes in child labor laws. According to Sheppard and Robbins (2007), there was "an approximate doubling of the high school population every 10 years from 1890 to 1930" (p. 201). This increase was matched by the loss of influence of the "mental training" view of education. Science teachers began to assert themselves as more than scientists: They were also educators. Writing specifically on biology, Sheppard and Robbins (2007) state that:

> *There was a rejection of the college dominance of the biological sciences as being abstract and impractical ... High school teachers wrote the new biology texts, and the biology syllabi were adapted to the developmental needs of students who would be in the earlier grades. The content of the course was more practical. (p. 201)*

For chairs in the early 20th century, this meant the evolution of an increasing responsibility for pedagogy, supervision, and administration. The situation, however, remained quite fluid as the trend toward teachers' disciplinary education produced departments staffed by specialists who reinforced the academic script of science education. Unsurprisingly, the first empirical studies into the role of the chair concluded that the position was in a state of confusion, with little agreement on either the chairs' function or the criteria for selecting chairs (Peacock 2014). Later researchers reported that that the sources of this confusion were not dealt with. Chairs were too busy with teaching and administrative trivia to focus on their main function of instructional supervision, and many chairs were not consulted on personnel issues affecting their team of teachers. In 1947, Lowry Axley compared the role of the chair to that of a racehorse burdened with the duties of a plow horse:

> *The departmental plan is based on specialization, but apparently very few systems make full use of the specialized training of heads of departments. The owner of a champion racehorse expects a championship*

> *performance when his horse is put to the test, and he would be considered a congenital idiot if he burdened his racer with the duties of a plow or draft horse in addition to his racing ... Their main function is lost sight of, and they are not given proper opportunities to use their training to promote the efficiency of their schools. (Axley 1947, p. 274)*

In the 1950s, research began to focus on the potential importance of the chair to improving the quality of instruction within the department. Rinker (1950) suggested that chairs should maintain a simultaneous focus on supporting students and teachers, while developing links to academic, professional, and school communities, while also performing clerical duties. This focus has continued to be developed over the past half century.

Latter Days: 1960s to the Present

In the 1960s, changes in research methodologies allowed researchers to investigate the chair's work and to analyze the relationships between the specific factors that affect that work. These methodologies developed even as the publication of Schwab's "The Teaching of Science as Enquiry" touched off an ongoing questioning about the meaningful purposes of science education. Given that the pressures for reform are only intensifying, the capacity to differentiate between aspects of the chair's work is an important step in understanding the role and the impact that it can have on teacher professional learning. While the earlier concerns about the role of the chair continue to be reiterated, there is an increasing awareness that "chairs are in an ideal position to facilitate instructional improvement because of their daily contact with teachers and their own instructional expertise" (Weller 2001, p. 74). This recognition is based on a number of factors. As science teachers are socialized into their departments, chairs are in a strong position to offer leadership around teaching and learning. Consequently, departments can represent an important site for professional learning and also function as a link between teachers and other science education organizations such as the National Science Teachers Association (NSTA), the National Science Education Leadership Association (NSELA), and university science education faculty. The NSTA position statement "Leadership in Science Education" outlines the roles that science leaders, including chairs, have in the implementation of reforms such as the *Next Generation Science Standards* (*NGSS*). Unfortunately, despite the growing awareness of the potential for chairs to provide leadership, they remain underused as a resource for improving instruction (Weller 2001). The overwhelming picture remains of chairs being asked to do too much with too little for too long—of racehorses continuing to be being burdened with the duties of the plow horse.

So, what does current research tell us about the leadership required of chairs in implementing reforms such as the *NGSS*? The recent work of Jeremy Peacock, a former science chair and a regional content specialist from Georgia, highlights four important leadership capabilities for contemporary science chairs who are seeking to provide instructional leadership in their departments.

Leadership Capabilities

Peacock worked through the research literature on the roles and responsibilities of the science chair from 1910 to 2013. This material has been analyzed using the concept of leadership capabilities that can be defined as the "seamless and dynamic integration of knowledge, skills, and personal qualities … [required for a] practical endeavor such as school leadership" (Robinson 2010, p. 3). From this work, four core leadership capabilities emerged as contributing to the ability of science chairs to offer science instructional leadership:

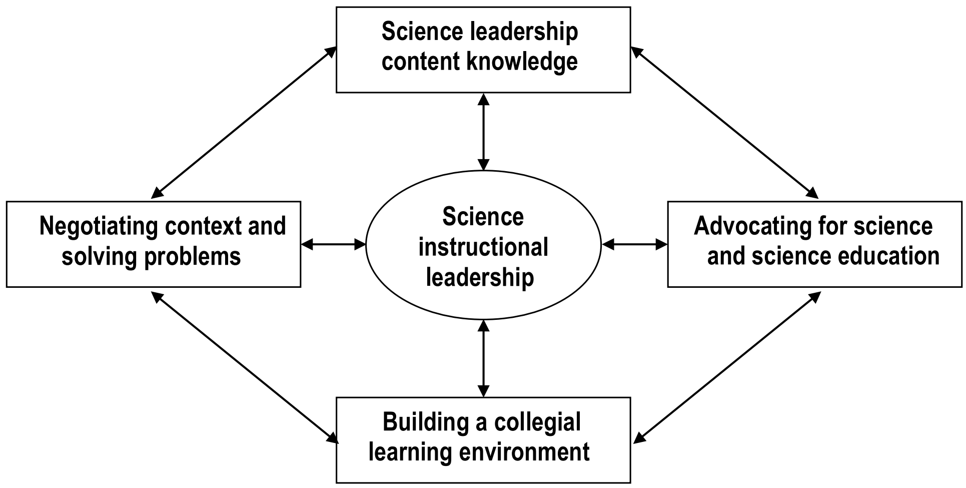
- Science leadership content knowledge
- Advocating for science and science education
- Building a collegial learning environment
- Negotiating context and solving problems

The relationship between leadership capabilities and instructional leadership is shown in Figure 3.1 (p. 52). Peacock makes the point that, while the leadership capabilities are interdependent and carry equal importance, the particular arrangement of the capabilities is intentional. Given that the role of subject-specific leadership is generally underrepresented in the literature, science leadership content knowledge is given prominence at the top of the figure.

The value of Peacock's work is that it draws from the literature to provide a guide to the capabilities that chairs need to work with if they are to reimagine the department. Our advice to chairs regarding these capabilities comes with two caveats. The first is that science leadership content knowledge, while underrepresented in the literature, is critical if a chair is to establish credibility for any reform proposals. One of the major issues that plagues the implementation of many reforms is that they appear disconnected from the work of teachers. Teachers place great store in credibility, and the best way to build support for any reform is to allow teachers to see the reform in practice. The second issue is that we, as science teachers, will never possess all knowledge in these areas, nor should we be expected to. If we are to reimagine the department, we need to be aware of our

Figure 3.1

CONCEPTUAL MODEL OF LEADERSHIP CAPABILITIES CONTRIBUTING TO SCIENCE INSTRUCTIONAL LEADERSHIP



Source: Peacock 2014, p. 43

strengths and limitations and work from where we are. Paralysis through analysis serves no one, least of all our students and colleagues. We learn by doing and (hopefully) from our mistakes, so these capabilities evolve over time, reflecting changes in our own knowledge, the impact of mandated changes, and the changes that occur in departments as teachers also learn. The important point is that the capabilities focus us on what is important in different yet interconnected aspects of our work as chairs. So, let's take a closer look at each of the capabilities.

Science Leadership Content Knowledge

It should be obvious that a chair possesses a comprehensive understanding of science, but in saying that we open up an important issue that is sometimes ignored. Reform documents such as the *NGSS* are clear that discrete knowledge of science concepts is no longer sufficient. Teachers must be more than content specialists—they should *also* be learned generalists with the capacity to link science to the world in which they and their students live. The NSTA position statements also increasingly reflect this growing change in emphasis. For example, read the statement "Quality Science Education and 21st-Century Skills" (NSTA 2011). This is a call to recognize and value the personal practical knowledge that all teachers bring to their work. Personal practical knowledge, derived from experience within both the profession and general life experiences, is foundational to teaching.

For chairs, this leadership capability centers on three factors. First, they should possess, and be constantly refining, their reform-based expertise in science content, the teaching and learning of science, instructional strategies, curriculum, and assessment. As the new NSTA position statement on the *NGSS* makes clear,

> *implementing the NGSS requires that experienced teachers make a significant shift in the content and manner in which they have been teaching and that beginning teachers make a shift from how they were taught at the university level. For many teachers a modification in the content knowledge and competencies will need to be made. (NSTA 2013)*

This expertise builds credibility and allows other teachers to see what reform-based instruction looks like. Second, establishing credibility allows the chair to start influencing departmental curriculum and instructional and assessment decisions. This influence arises as the chair begins to facilitate reform-based learning opportunities for their teachers in areas such as instruction, curriculum, assessment, and student learning. Finally, if a chair is developing this capability, then he or she is in a better position to discern what is an educational fad versus what changes need to be made to improve student learning in every classroom.

Advocating for Science and Science Education

The links between departments and faculties of science have had a great influence on the historical development of departments. In 1950 Rinker expanded on these connections, suggesting that chairs should develop and maintain links to science in the wider community and be prepared to act as advocates for science. This is an important capability for three reasons. The first is that the development of links between the department and the wider scientific community opens opportunities for students to see science as occurring beyond the classroom. The NSTA position statement "Learning Science in Informal Environments" states:

> *The learning experiences delivered by parents, friends, and educators in informal environments can spark student interest in science and provide opportunities to broaden and deepen students' engagement; reinforce scientific concepts and practices introduced during the school day; and promote an appreciation for and interest in the pursuit of science in school and in daily life. (NSTA 2012)*

Secondly, chairs can advocate for science, the teaching and learning of science, and increased public understanding of scientific concepts. This is particularly important when confronting issues that may be contentious within society but not within the scientific community. The actions of the Dover Area School District biology teachers who refused to read the statement that "Because Darwin's theory is a theory …" in 2004 is one of the more extreme examples of teachers having to advocate for their discipline and profession.

Finally, to lead reform, chairs need to be actively engaged with developments in science education. Engagement is vital because it provides a frame of reference to gauge the position and performance of the department relative to what is being mandated by the reform documents. The relationship between science, science education, and society has changed. Without an understanding of those changes, and an awareness of the alternatives to what currently happens in their departments, chairs may not be able to see beyond their concerns with the covering of the curriculum to the wider issues that they should be addressing.

Building a Collegial Learning Environment

A collegial learning environment is far more than a place where teachers enjoy the company of their colleagues. Chairs have the key role in shaping departments as places where teachers share a responsibility for the continuous improvement of student achievement. Such an environment has three characteristics, the first of which is the need for a focus on both teachers' content and pedagogical knowledge and students' ways of learning content. Second, there must be opportunities for teachers to engage in active learning through activities such as mutual observation and critique, the collaborative implementation of innovations, and opportunities to review student work and assessment and communicate these to other teachers. Third, learning opportunities need to be coherent with what teachers already know and work from that point to move toward the ideals of reform documents such as the *NGSS*. A collegial learning environment is one in which teachers are prepared to learn how to analyze their own and each other's instructional strategies, consider the links between teaching and learning, and experiment with alternative instructional and assessment strategies. To develop a department along these lines requires the chair to take a leading role in modeling these qualities while also being aware of the context in which their department operates.

Negotiating Context and Problem Solving

Chairs are impacted by a range of sociopolitical forces (and their attendant values) including those that operate within the school, the national education policies, and the complex range of forces that are conveniently grouped under the banner of globalization. All of these have some effect on the work of the department. The challenge for the chair is to negotiate through these forces and simultaneously work to improve teaching and learning and meet the demands of policy. This is never an easy task, and there are times when the wrong decision will be made. The best advice that we can offer is to work with your department to make the most morally defensible decision that can be made in support of any movement toward the ideals of the reform documents. Sergiovanni (1992) has described five bases from which leaders can draw their power: bureaucratic power, based on rules and regulations; technical-rational power, based on the leaders' knowledge of the field; psychological power, based on knowledge of human relations; professional power, based on professional norms and standards; and moral power, based on clearly enunciated values and the shared norms of a community. In part, leadership involves making political decisions and having the power to carry them through, and the chair who maintains a moral presence is more likely to shape the department as a community committed to improving teaching and learning and reimagining the department toward the ideals of the reform documents.

Peacock's model gives us an understanding of the capabilities that chairs need to bring to, and continue to develop in, their role. Leadership is about people, and the capabilities that we have discussed here all contribute to developing the conditions that allow departments to act as places for teachers' long-term professional learning. How those capabilities can be brought together as a coherent whole is the focus of the next section.

The Department and Leadership

One of the key principles that directed the writing of this book is the belief that individual science teachers struggle to align their work with the practices outlined in documents such as the *NGSS*. In saying this, we are not questioning the commitment of any science teacher; rather, we understand that the academic traditions the overwhelming majority of us have been socialized into make it profoundly difficult for us as individuals to make the sorts of changes to instruction envisaged by the reform documents. We also believe that departments, as both communities and organizations, possess many of the qualities needed to support the professional learning of all science teachers, and that the role of the science chair is crucial in realizing that potential.

Let us be clear, professional learning is more than the acquisition of knowledge; it is a preparedness to question current pedagogy and develop new instructional strategies that improve the quality of teaching and learning. Yager (2005) states that "the focus of teachers' learning should be one of inquiry into teaching and learning. This, of course, emphasizes the use of questions that leads to learning and the identification of possible answers" (p. 17). At its heart, therefore, the importance of the department to professional learning lies in its capacity to develop as a trusting environment in which teachers are free to question the teaching and learning of science. Such an environment provides

> *opportunities to voice and share doubts and frustrations as well as successes and exemplars. They need to ask questions about their own teaching and their colleagues' teaching. They need to recognize that these questions and how they and their colleagues go about raising them, addressing them, and on occasion even answering them constitute the major focus of professional [development]. (Lord 1994, p. 183)*

This quote raises two important questions: What does this environment look like, and is there some process to facilitate opportunities for learning? To answer these questions, we return to our conceptualization of the department as being a community and organization simultaneously. As we saw in Chapter 1, this dual conceptualization enables the chair to choose the appropriate cultural or bureaucratic strategies, or some combination of both, to pursue the aim of reimagining the department.

As a community, the department has a primary role in shaping teachers' instruction. This does not imply that all teachers in the department will share identical images of science or science education (see Wildy and Wallace 2004). However, as science teachers, they all share a particular identification with the discipline and subject. It is this common identification that serves as the starting point for conversations into the teaching and learning of science. The aim of these conversations should be to develop a consensus of what is important in science education and from there establish clear goals for teaching and learning. It is the development and communication of these goals that becomes the source of political power of the department as an organization.

In conducting conversations around the teaching and learning of science, remember that resources such as the *NGSS* and the NSTA position statements, work with board and state or provincial science specialists, and attendance at conferences can all provide valuable insights and supports for teachers and chairs looking to make changes to their instructional and assessment strategies. There is no justification for reinventing the wheel. Without input from outside the department, there is a real risk that conversations can be used to reinforce the status quo. Therefore, the chair must be prepared to use the position to shape the conversation toward the goals of the reform documents and his or her vision for the department.

Transactional Leadership

The initial steps in shaping the department as a community involve understanding where teachers are in their professional (and to some extent in their personal) lives, their understanding of teaching and learning, and their learning needs. Initially, this may well involve the chair in self-interested exchanges with self-interested others and being prepared to bargain with teachers whose "interests and claims serve their own goals primarily, and only secondarily, if at all, serve the interests of the organization" (Starratt 1999, p. 26). Realize that there will always be some teachers who are set in their ways and reluctant to change, if they will change at all. As chair, you will win some, and you will lose some. Don't take it personally and never lose sight of the bigger picture.

The leadership literature refers to this as transactional leadership, and it is really about establishing the ground rules by which teachers can participate in the work of reform. This form of leadership is concerned with the bureaucratic issues of supervision and organization to promote "a routinised, non-creative but stable environment" (Silins 1994, p. 274). In establishing these ground rules, there must be a commitment to values such as integrity, honesty, trust, wisdom, and fairness and to the needs and rights of all involved. Central to these conversations must also be a sharing of instructional strategies and beliefs with other teachers and a constant message that the student success in learning and assessment tasks is the absolute priority in everything the department does. Setting the ground rules through transactional leadership is an important first step in shaping the community, but it will not by itself lead to long-term commitment, and there will be times when the chair will have to revisit the ground rules. Teachers come and teachers go, and as issues arise, the ground rules will need to be reset. The importance of transactional leadership is that it sets the stage for the department to move beyond being a collection of science teachers toward being a community of science teachers who are prepared to reconsider their instructional strategies in light of the reform documents. This brings us to what is known as transitional leadership.

Transitional and Transformational Leadership

To effect long-term change requires personal commitment. Teachers need to know that the chair is supportive of them and their work; the chair must establish a "moral presence" (Starratt 1999). Such a presence is grounded in how the chair works with his or her teachers and must reflect the virtues of honesty, courage, care, fairness, and practical wisdom. The conduct of the chair is crucial in building respect and a sense of loyalty, both of which are foundational to any movement beyond transactional leadership toward transitional and transformational leadership.

Transitional leadership moves beyond the stability of transactional leadership and begins to challenge the status quo of individual and departmental teaching and learning. It does this by beginning to draw on the (perhaps latent) abilities of teachers to create new standards of expertise and collegiality, shared values and beliefs, and a shared commitment to the work of the department. It is this shared level of commitment that gives the department its political power. A strong department is one that is characterized by "individual and communal empowerment … involves the gradual embracing of responsibility for one's actions. It involves autonomous individuals in the choice to be active, rather than passive" (Starratt 1999, p. 29).

It is also one in which the difficult decisions that often have to be made about teaching and learning and issues such as resource allocations can be made in an informed way. The conduct of the chair continues to be crucial at this stage for a number of reasons. Teachers need to be able to trust in the chair that it is acceptable to make and learn from mistakes. The realignment of relationships (e.g., from individualistic teacher to colleague) and the professional conversations that underpin that realignment must be based on honesty and care. For teachers to move beyond the pedagogies that have served them well in the past and to embrace new pedagogies is an act of courage. It is also a stage that is risky and cannot be rushed. Starratt (1999) suggests that the transitional stage may take two to four years. In our experience and working with other chairs, this time frame may be on the optimistic side. Sustained over a period of time, transitional leadership can take on aspects of transformational leadership, which

> *seeks to unite people in the pursuit of communal interests. Motivating such collective action are large values such as community, excellence, equity, social justice, brotherhood, freedom. Transformational leaders often call attention to the basic values that underly the goals of the organization, or point to the value-laden relationships between the organization and the society it serves. Transforming leadership attempts to elevate members' self-centered attitudes, values and beliefs to higher, altruistic attitudes, values and beliefs. (Starratt 1999, p. 26)*

Given that one of the main objectives of reform documents such as the *NGSS* is to overcome the growing distance between an academic science education and contemporary students, we believe that transformative leadership at the departmental level is crucial. Only when teachers understand the need to change, are presented with viable options for change, and work in an environment where they can safely take on an increasing personal responsibility for shaping and living the values and interests of reforms will change be sustained. We would caution, however, that the shift from transactional to transitional and then transformative leadership is never linear; there will be movement backward and forward. Departments are never static, so the chair must constantly be proactive in developing opportunities for teachers to revisit and renegotiate what is important to them as a department in light of their growing expertise in working with the reform documents. This requires knowledge of the predominant departmental structures that exist for contemporary science departments and how those structures can influence leadership.

Departmental Structure

Busher and Harris (1999) have investigated the structure of departments and the implications of those structures for the leadership of the chair. Of the five structures they describe, two are of particular importance to science. Both structures are characterized by having a number of teachers and access to a range of resources. The first structure, the "unitary" department, is more likely to be found in smaller secondary schools in which there is a limited differentiation of science into its component areas. In such departments, the chair can exercise a strong and direct influence on the teaching and learning that occurs. The other structure, the "federal" department, is more likely to be found in larger secondary schools and may consist of specialized subject leaders tasked with shaping teaching and learning for their specialization under the aegis of the department. In a federal department, the chair needs to supervise and coordinate the work of these specialist leaders within the framework of the whole department. Federal departments generally work because "their subjects and pedagogies are perceived as cognate and their cultures are substantially homogeneous" (Busher and Harris 1999, p. 309). The different structures, however, clearly place different leadership demands on the federal chair compared with their unitary counterpart.

Unitary departments, given their generally smaller size, require leadership from the chair that balances and prioritizes the needs of various courses within the science program. This requires a level of skill in dealing with political demands for resources and developing the formal and informal strategies for coordinating teaching and learning with the needs of students. In contrast, federal departments require leadership at both the specialization and department level. Important factors to consider with these departments include the history of the department's development and the consequent impacts on the formal and informal distribution of both power and authority. It is not difficult to visualize a long-serving teacher in an area both possessing and being willing to use their influence to protect or promote the interests of their specialization. In an earlier work, one author of this book reported on a chair who acted as a mentor for a teacher who subsequently became a chair:

> *Will related that the teaching of school science in the mid-to-late 1960s was rigidly organized into scientific sub-disciplines: "I was a biology guy, and my first departmental chair was a physics guy—physics guys and biology guys don't think the same way, and we don't pretend to." This siloing of knowledge was obvious to Dan when he started teaching in 1982: "Teachers guarded their territories within science. So a physicist was a physicist, a chemist was a chemist. And we had grade nine and ten courses that you had to teach, but you always taught it from your perspective. It was a big competition, I think, to see whose science was best and where the kids ended up. Which science will they pick?" (Melville and Bartley 2010, p. 812)*

If working in a federal department an important point to note is the extent to which the chair, at the center of the department has, and is recognized to have, sufficient power to lead. Without power to effect change, leadership will not happen. And that brings us to the final section of this chapter, the relationship between chairs and those external decision makers whose demands so often impact the work of the department.

The Chair and External Forces

As we all know, reforms in education often appear to come and go, and the more cynical among us believe that the more things change, the more they stay the same. Science education has not been immune to this, and reform efforts have attempted to respond to the growing disconnect between science, science education, and society by explicitly outlining how teachers and their classrooms need to change. Given the resilience of the academic tradition in science, we could argue that documents such as the *National Science Education Standards* and the *NGSS* have been very good at saying *what* should be taught, yet have fallen short in understanding the *how* of enacting and supporting these reforms. This is particularly important for chairs because they are often under pressure to simultaneously provide instructional leadership in the department while implementing a range of curriculum and administrative changes. These changes can come from the school, board, state, and national level, and sometimes appear contradictory to the teaching and learning of science. How the chair responds to (or positions him- or herself in relation to) these external forces is crucial if the department is to maintain a focus on improving the teaching and learning of science. To consider how chairs can position themselves in relation to reform initiatives, we turn to the work of the French sociologist Pierre Bourdieu.

The position of the chair to reforms is influenced by both their personal dispositions to the reforms and what the department as a community and organization sees as good science teaching. For most departments, this is a continuing attachment to the traditional script. The strong personal and professional relationships found in departments allow them to be considered social spaces or "fields" (Bourdieu 1990). Fields can be conceptualized as specific social environments "with explicit and specific rules, strictly delimited in … time and space" (Bourdieu 1990, p. 67). As social constructs, fields are made up of individuals who share common beliefs and practices and compete for symbolic and material products or "capitals" (Bourdieu 1984). Extending the concept, schools, boards, and reforms such as the *NGSS* can all be seen as fields with their own particular rules, priorities, and values. These fields are never independent of each other—they all overlap and exert an influence on teachers and classroom teaching and learning. Fields come into conflict and competition when what is valuable to each is challenged. If a reform is seen to challenge the instructional strategies that are valued by a department (and are seen as foundational to the department's power and prestige), then the reforms will be resisted. That resistance can take many forms, from rejection to coopting the reform to the values of the department. Alternatively, a reform that is seen to reinforce the values of the department will be accepted. To a large degree, the response of the department to reforms relies on the leadership of the chair and his or her ability to understand the relationships between the "power structures, hierarchies of influence, and … practice" of both the department and the reform (Lingard and Christie 2003, p. 320).

In working with 12 science chairs in the southeast United States, Peacock (2013) identified two major constraints on chairs as they sought to understand and implement external reform efforts. These are important to understand in terms of highlighting the pressures that chairs face and the courses of action that are possible when dealing with reforms. The first constraint was how a chair's school context shaped his or her capacity to act as an instructional leader. Specifically, their position within the school leadership hierarchy constrained their leadership. Four types of leadership were identified: the chair as liaison, informal shared leadership, formal shared leadership, or the chair as autonomous leader. At one end of the hierarchy, the chair as liaison implements school (or board) administrative initiatives within their departments. In the second group, chairs who have negotiated greater authority exert a more active influence on instructional practices. The third group possesses a formal leadership position that gives direct access to school-level decision making. The final group enjoys some level of autonomy from school-level administration in shaping the direction of their department. In presenting these groups, we are aware that the chair's position within the hierarchy of the school is not fixed, since changes within senior administration, staffing, and the changing issues that a chair faces can (and do) affect relative positions in the hierarchy and the responses that are required of them.

The second constraint was the influence of general education reforms on science chairs. Rather than seek to engage with science reforms, chairs were spending their time and effort addressing questions of assessment, accountability, and school improvement. Consequently, they were limited in the leadership they could provide in support of science education reforms.

We can learn from the experiences of the chairs in this study through a consideration of their words. To do this, we would like to offer a short vignette (drawn from Peacock 2013) from each of the leadership approaches we have described in this section and how they attempted to connect the work of their department to the wider reform efforts in science education.

Brad: The Chair as Liaison

Brad saw his role of chair as a liaison whose principal duty was to "push the administrator's agenda" within his department:

> *There was a big push in the district for teaching science with inquiry. I was pretty excited about the possibilities [and] initiated a program in which a group of teachers would go through the curriculum and identify specific ways to infuse inquiry-based strategies into the district curriculum. The group worked very hard trying new things, planning activities, and discussing outcomes. Ultimately, it all fizzled. Administrators and teachers ultimately didn't buy into the effort. I have come to believe that good standardized test scores are really all that matters to the bureaucracy. If the test scores in the paper look good to the public, initiatives from the grassroots aren't going anywhere—even when they would be good for students.*

Consider Brad's position for a moment. He was excited about the teaching of science as inquiry and had the freedom to initiate a program that encouraged teachers to try new strategies. And yet, in his own words, the effort ultimately "fizzled." But why? Have you, or your department, ever been in the position to enact a district agenda and given the resources to do it? What happened, and more importantly, why did it happen? What is the responsibility of the chair in such a situation? We would suggest that, when implementing a district (or state) agenda, how you view the role of the chair is crucial. In this vignette, Brad saw his role as implementing the district agenda rather than as an instructional leader. Consequently, his understanding of the reforms and how they could be translated to the classroom was limited. While Brad viewed the inquiry initiative positively, he had not instituted the change and did not display a long-term commitment to transforming science teaching. Second, Brad appeared to lack both the time and influence to challenge the teachers' and administrators' perceptions of the reform. To challenge the status quo requires power and influence to be wielded for considerable lengths of time: a one-year appointment is not credible. Further, the strategy that Brad implemented indicates a limited capacity to integrate the work of the department and the reforms. Without a strong understanding of the reforms, the decision to "go through the curriculum and identify specific ways to infuse inquiry" indicates an oversimplification of the complexity of inquiry and teacher professional learning. Similar concerns will arise with the *NGSS* and its emphasis on practices. What can you learn, or need to learn, from Brad in terms of your understanding of reforms and how to introduce them to your department?

Charles: Informal Shared Leadership

Charles was in the position of, having been elected to the position of chair, also being responsible for conducting the school teacher performance evaluation process. Within his school, elected chairs experienced little support from school administrators. The teacher performance process was seen as poorly designed, with positive ratings being perceived as doing well due to the teacher's efforts, while negative ratings were perceived as punitive and not the responsibility of the teacher. The net result was that long-term professional learning was not encouraged. Consequently, Charles saw the role of chair as intensely political, balanced between influencing and alienating the teachers in his department. Charles also reported that his main concerns as chair were laboratory and chemical safety and student participation in science fair competitions. Important as these are, they are not reform issues. For Charles, the implementation of the *NGSS* was reduced to a question of content: "We will need to rework our curriculum maps …" Charles did discuss several examples of instructional leadership within his department. In particular, he attempted to introduce teachers to a series of board-mandated content literacy strategies:

> *I'm going to target the ones who are struggling. Now, you have to be very subtle because I don't have any ability to make anybody do anything. I can give [poor ratings] now and then, but it's just punishment; the rating system is not designed very well. The teachers will just say, "We*

> *don't want you anymore." As I've been trained in the reading across the content area, I can take some of those literacy strategies and say, "Hey, let me show you this." I'll just show it to them, and then they try it, and they'll talk about and say, "Well, this was the problem." What I'm trying to do is repair the places that I think need repair, whereas they will try the strategy and then forget about it.*

Charles believed that his work as chair was limited by the "top-down approach from the central office" in which administrators directed a series of general literacy and assessment initiatives. Charles' position is more common than we would like to admit and is a major source of stress and frustration. As a reality for many chairs, situations like these raise several issues. Before reading any further, what issues does Charles' dialogue raise for you? What are the leadership capabilities that need to be evident (or developed) in a situation like this? To what extent is Charles's perceived lack of influence indicative of a greater need to understand the department as a community? By this we mean that the chair needs to understand where teachers are in their professional (and possibly personal) lives, their understanding of teaching and learning, and their learning needs. Effective instructional leadership is based on an understanding of people, both teachers and students, and their learning needs.

Kim: Formal Shared Leadership

As a department chair, Kim occupied a formal position in the school leadership, with access to school-level decision-making processes. At the time of the study, the administration was focused on the use of student assessment data as a basis for decision making. Consequently, the focus of her work was closely aligned to the goals of the school, not the department. Her departmental leadership was evident in the operation of a STEM (science, technology, engineering, and mathematics) academy within the school and working with her district science coordinator in providing active support for science teachers.

> *As part of the STEM academy, I have been working to increase inquiry-based learning, depth of content knowledge, and reading and writing across the curriculum. The purpose is to get students to develop a deeper understanding of content material and to be able to communicate and apply those ideas to other areas. The* NGSS *will definitely add to the supporting framework to help all teachers improve mastery of standards, even if they are not in the labeled STEM courses. We will use the* NGSS *standards to provide an additional framework in conjunction with the* Common Core *standards.*

For chairs, who operate in the middle management of the school, this can raise a question of loyalties: to whom do you owe your loyalty, the school or the department? This question is fraught with danger, as Kim's vignette demonstrates. While Kim appeared to exhibit an understanding of science education reforms, including STEM and inquiry-based learning, there was a discrepancy between her words and the future of science education described by the reform documents. The first discrepancy was her approach to the reforms, which could best be described as mechanistic: "We will use the *NGSS* standards to provide …" The *NGSS* were portrayed as a checklist to prepare students to meet the *Common Core State Standards*, not as a long-term strategy for improving the teaching and learning of science. The second discrepancy was the unwillingness to challenge the academic script: The administrative focus was on assessment- and data-based instructional interventions, not on science education reform. Consequently, Kim mounted little challenge to tightly held beliefs, and the department remained on the periphery of science education reforms.

Fortunately, loyalty is not a zero-sum game, but it does require that chairs ask questions of themselves, their departments, and administrators. These can include questions such as the following:

- How can reform in the science department align with the aims and goals of the school?
- How do we understand student success in science, and how does that translate across the school?
- How can the professional learning opportunities in the department meet school-level professional learning objectives?

Melanie: The Chair as Autonomous Leader

Melanie was the chair of a department that had considerable freedom to chart its own course: "Nobody gets in our way much." With the support of her administrators, Melanie gave the teachers in the department the authority to pursue their own agendas. One outcome of this was the formation of a math–science academy within the school. Melanie herself took the primary lead for the physical science courses in her department, while relying on another teacher to lead the life science courses.

> *I went to one of the STEM programs that help with resources, and I started a robotics team because I'm trying to get an engineering design course this year. I'll be teaching that and going to camp with some of my students. We're also going to learn engineering design processes. ...*

> *The other teacher is doing something similar, but he wants to do more project-based teaching within biology, and so a few years ago we started a math–science academy. It is supposed to be a capstone project at the end, but we haven't been allowed the time for them to work on this.*

Melanie wielded considerable power in her efforts at instructional improvement, but her efforts did not represent a specific commitment to the reforms described in the *NGSS.* The changes within the department were somewhat superficial and lacked the coherence of the reform documents. Teachers, free to hold individual perceptions as to the meanings of the reforms, may implement changes consistent with the reform but are more likely to adapt the language of the reforms to their existing instructional strategies (Stigler and Hiebert 1999). To be a chair is to accept the responsibility for the teaching and learning of science within the department. This means that you need to make value judgments as to what is important, and then see these decisions through. There is no easy way around this. If you are to successfully reimagine the department, then *why* are the reforms important to you, your students, and your colleagues? Answering that question will help you shape a coherent response to the external forces that impinge on the work of all chairs.

Learning From These Chairs

What can we draw from the positions that these chairs held toward external forces? The first lesson is that chairs need to have a solid understanding of a reform before they attempt implementation. Although the *NGSS* documents recognize that it is the teachers' responsibility to enact professional autonomy, there is a focus on prioritizing the engagement of students with the science and engineering practices, disciplinary core ideas, and crosscutting concepts. To achieve this focus, it is necessary for the chair to understand and identify these essential framing principles of the *NGSS* so that as the department undertakes reforms (as with Melanie's math–science academy) the *NGSS* can serve as a compass and measure of success. Documents such as the *Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric for Lessons and Units: Science* (NGSS Lead States 2014) can serve to help keep *NGSS* central to all design work and discussions around teaching and learning.

Without tools to help guide the work of reform, the risk of possessing a superficial knowledge is twofold: It will either not engender real commitment or will be misinterpreted and run the risk of becoming coopted into existing practice. Chairs need to have an understanding of how to wield power and position in the promotion of reform and have the ability to prioritize their efforts. They also need to have the capacity to operate simultaneously and strategically within, and across, both the department and the reform. This involves developing the leadership capabilities that we discussed earlier: science content leadership knowledge, advocating for science and science education, building a collegial learning environment, and negotiating the context and problem solving. It is easy to write these words; it is much harder to live them, especially when faced with competing reforms. In the next chapter we start the journey toward putting these words into practice.

Summary

- The role of the science chair has historically been ambiguous. There is something of a consensus that the role involves a simultaneous focus on clerical duties, supporting students and teachers; and cultivating links to the wider academic, professional, and school communities.
- Leadership capability requires an integration of knowledge, practical skills, and personal qualities.
- For science department chairs, capability is required in four areas:
    1. Science leadership content knowledge
    2. Advocating for science and science education
    3. Building a collegial learning environment
    4. Negotiating context and solving problems
- Teacher professional learning is more than the acquisition of knowledge. It is a preparedness to question current instruction and develop new instructional strategies that improve the quality of teaching and learning.
- Departmental leadership is iterative, never static or linear. Depending on the context, chairs initially need to engage in transactional leadership, which sets the ground rules by which teachers can participate in the work of reform. Bureaucratic issues of supervision and organization need to be worked through at this stage. More importantly, chairs must demonstrate a commitment to values and the individual's needs and rights. Such a commitment is demonstrated in the sharing of instructional strategies and beliefs, and a constant message that the learning of all students is the department's absolute priority.
- Transactional leadership will preserve the status quo. If reform is to occur, then chairs need to draw on the abilities of teachers to create new standards of expertise and collegiality, shared values and beliefs, and a shared

commitment to the work of the department. This is transitional leadership and may take three or more years of work.

- Transformational leadership will only occur when teachers understand the need to change, are presented with viable options for change, and work in an environment where they can safely take on an increasing personal responsibility for shaping—and living—the values and interests of the reforms for the benefit of their students.
- The shift from transactional to transitional and then transformative leadership is never linear. There will be movement backward and forward. Departments are never static, so the chair must constantly be proactive in developing opportunities for teachers to revisit and renegotiate what is important to them as a department.
- Chairs need to understand the structure of their department and how that affects the politics of their work. Unitary departments require skill in dealing with the political demands for resources, and the coordination of teaching and learning with the needs of students. Federal departments require leadership that considers these departments' history and the distribution of both power and authority.
- The chairs' position within the school's administrative structure can shape the work of the chair. Chairs can occupy positions such as liaison, informal shared leadership, formal shared leadership, and autonomous leader. These positions are not fixed; changes in personnel and situation can affect the role of the chair.
- Chairs are also impacted by the time and effort required in response to general education reforms. These can limit the leadership that chairs could provide in support of science education reforms. Although chairs represent an important potential resource for supporting reforms, many chairs are seriously constrained in their ability to fulfill this potential.
- Chairs who are looking to reimagine their department need to have a solid understanding of a reform before they attempt implementation. Second, chairs need to have an understanding of how to wield power and position in the promotion of reform, and the ability to prioritize their efforts. And third, chairs must have the capacity to operate simultaneously and strategically within and across both the department and the reform.

Where Am I Today? Questions to Ask Yourself

For You as a Science Teacher

1. What does professional learning mean to me, and what responsibility do I take for my own learning?
2. How can I contribute to the professional learning of my colleagues?
3. What can I learn from my colleagues, and how can I establish those relationships?
4. In what ways might my actions around questions 2 and 3 help me to generate a culture of trust among department members?
5. What is my active involvement with professional associations such as NSTA?
6. What can I learn from the chairs whom I have worked with? What were their strengths and weaknesses? What would I do differently?

For You as a Department Chair

1. How do I see the role of the chair, and what do I really want to achieve over the coming year? the next three years? the longer term?
2. How do I prioritize my work as a chair?
3. What do I understand by the term leadership, and what do I need to learn?
4. What is the structure and history of the department? How do these influence the decisions that are made?
5. Who in the department possesses (and uses) power and authority? To what end is that power used?
6. What do I understand moral presence to be, and how would I seek to establish it?
7. What external forces do I have some influence over, and what is beyond my influence?
8. In terms of the leadership capabilities, what do I already do well, and what evidence is there for this judgment?
9. What leadership capability should I initially focus on developing? What resources will I need to develop my expertise in this capability?

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

Reimagining the SCIENCE DEPARTMENT

If you want your science teachers to have the freedom and capacity to truly make their teaching more effective, *Reimagining the Science Department* is the book for you. It provides both the context and counsel to help you change the departmental factors that don't support teaching and learning.

Reimagining the Science Department will accomplish several tasks:

- Offer practical advice about strategies that will influence the teaching and learning of science within your department. This advice is strengthened by practitioner vignettes and appropriate research.
- Give you historical understanding of how departments have developed, how that has shaped their capacity to influence teaching and learning, why we teach science as we do, and why that perspective is being challenged and found wanting.
- Explain how the role of the chair has developed and can be refocused on developing the leadership capabilities that chairs should have to lead learning within the department.
- Provide suggestions for gaining the support of school administrators—support that is critical to any chair.

If you are already a department chair or aspire to become one, *Reimagining the Science Department* will help you understand the importance of the position and develop your ability to lead. School administrators or school board members will find it deepens the commitment to developing a department in which the practices of science are taught for the benefit of all students.

Grades 6–12

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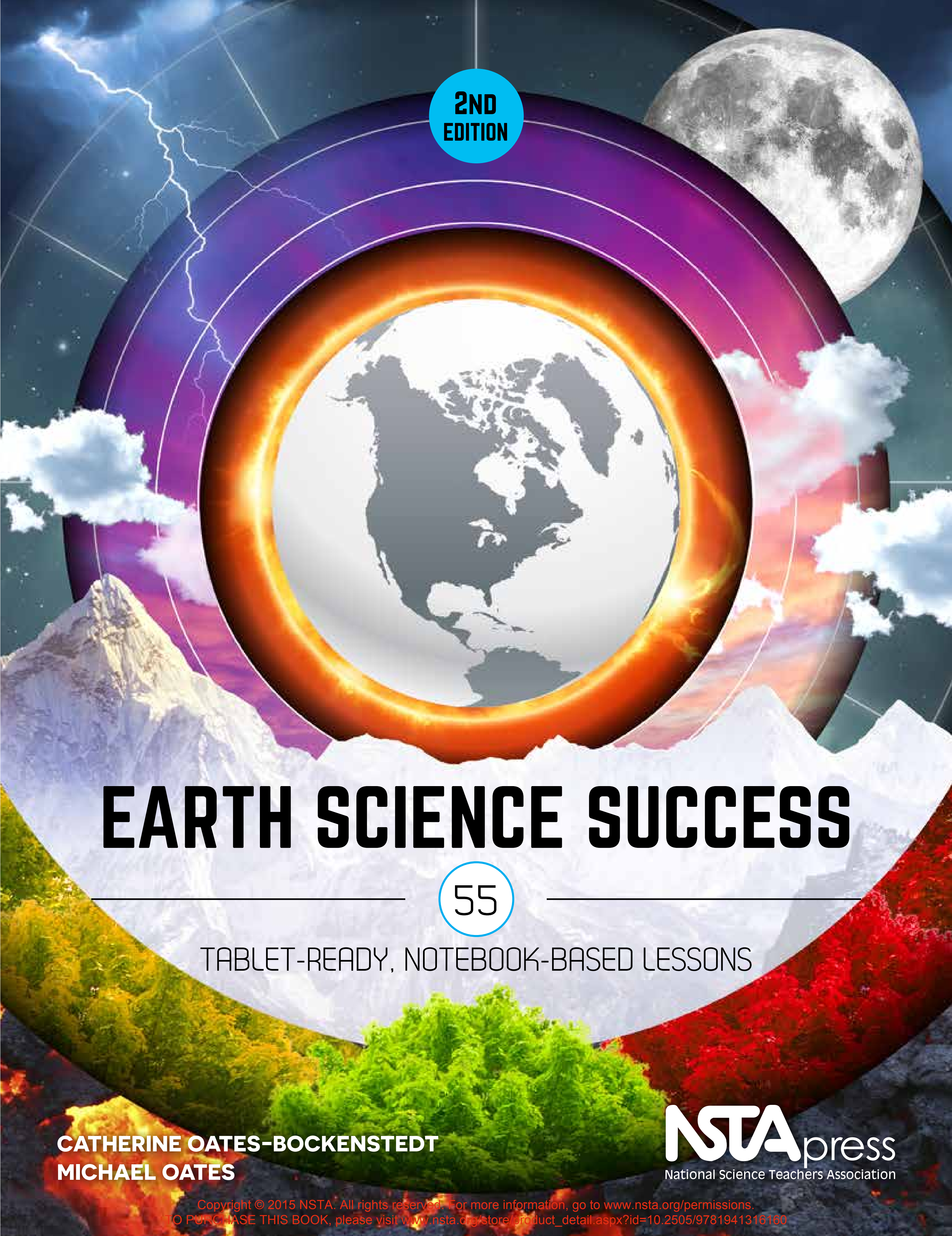

2ND EDITION

EARTH SCIENCE SUCCESS

55

TABLET-READY, NOTEBOOK-BASED LESSONS

CATHERINE OATES-BOCKENSTEDT
MICHAEL OATES

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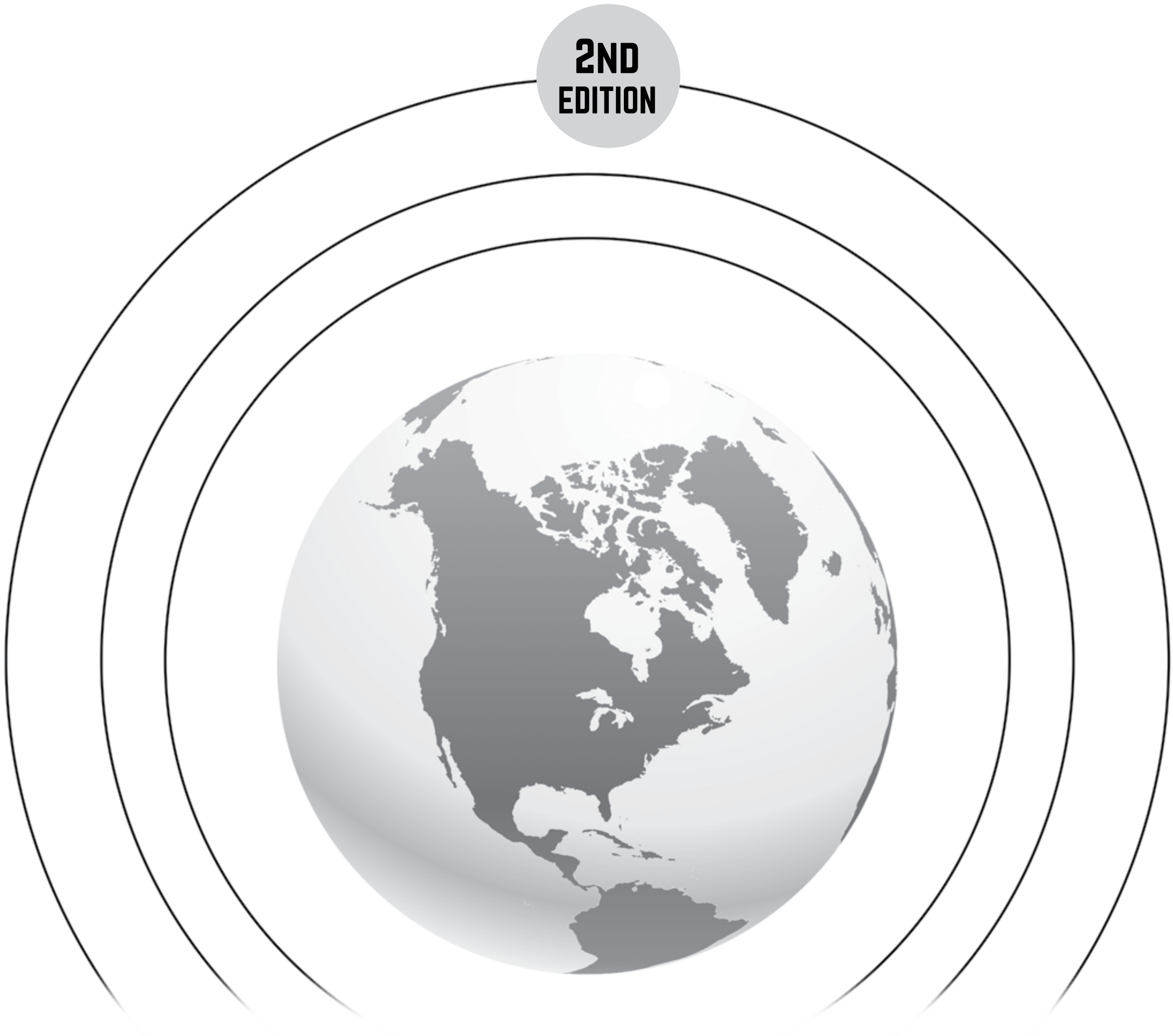

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"THE ART OF TEACHING IS THE ART OF ASSISTING DISCOVERY."

MARK VAN DOREN (1894–1972)

This book is dedicated to the power that
collaboration has among classroom teachers.
Special mention goes to my friend, Mary Gallus,
for her enhancement of lessons and
expert collaboration.

Introduction

This second edition of *Earth Science Success: 55 Tablet-Ready, Notebook-Based Lessons* provides a one-year Earth Science curriculum with 55 classroom-proven lessons designed to follow the disciplinary core ideas for middle school Earth and space science from the *Next Generation Science Standards* (*NGSS*). Intended for teachers of grades 5–9, *Earth Science Success* emphasizes hands-on, sequential experiences through which students discover important science concepts lab by lab and develop critical-thinking skills. Whereas the first edition focused more on the rationale for implementing the curriculum and the wisdom of using composition notebooks, this second edition focuses a special lens on the lessons themselves. The 55 lesson plans enable teachers to use electronic tablets, such as iPads, with best practice, field-tested methods.

Middle school Earth science teachers' days are very busy with large classes, meetings and various duties, grading and correction, class preparation, answering communications from parents, and so on. *Earth Science Success* is the result of the authors' desire to create a notebook-based, lab-focused, ready-to-use, and now tablet-ready curriculum that has been field-tested and refined for success. The authors have organized this curriculum into a series of investigations that emphasize the active involvement of students in a discovery process. Intended primarily for classroom science teachers as a survival guide for teaching a full Earth science course, *Earth Science Success* follows a three-step pattern of active involvement in the discovery process, which includes anticipation, evidence collection, and analysis. The topics chosen and the laboratory approach employed in *Earth Science Success* reflect the core ideas involved in scientific and engineering practices, which lead to the four main categories of performance expectations from *NGSS*: Engineering Design, Earth's Place in the Universe, Earth's Systems, and Earth and Human Activity. *Earth Science Success* is also a valuable tool for training future science teachers, who will enjoy implementing and discussing the investigations featured in this book.

To the Earth Science Teacher

Like you, the author is a busy classroom science teacher. Successful strategies include those that save time and promote skillful organization. Both composition notebooks and electronic tablets offer tremendous opportunities in this regard. The lessons in *Earth Science Success* lend themselves toward either approach. Combining the two, however, is even better.

The same successful pattern is followed for each lab report, no matter what the learning target or concept. See “Expectations for Each Investigation,” p. XIII, for a summary of the expectations for each component of the lab report. The point value shown in parentheses is flexible, and is based on a 30-point total for each lab report grade.

Among iPad apps, *Paperport Notes*, *Evernote*, and *Notability* all provide for fully integrated note taking. The author uses the *Notability* app with the Divider set as Science, and the Subjects set as Labs and Lessons, Reference Pages, and Glossary. She creates a PDF of each lab report template and posts it on her website (both *Google* and *Schoology*), for students to download. She encourages “auto syncing” to *Google Drive* or *Dropbox*, so if a glitch happens with the electronic lesson, the work has been backed up. Students submit their assignments electronically to *Schoology*, but *Showbie* and *eBackpack* also work well in that capacity. These Learning Management Systems allow teachers to “push” the assignments onto the students’ tablets, and provide due date calendar systems, as well.

The author uses a mini-conference method for typical in-class grading. This involves collecting all of the iPads (or composition notebooks with bookmarks placed in the current lab) in the front of the classroom, on a cart. The lab reports are graded in random order, while students work on other assignments and lessons, such as the graphing or analysis portions of the following lab, at their desks. Students are called up to sit next to the teacher, to witness the grading, as individuals, in a semiprivate conference. Input from the student and feedback from the teacher become clear and lasting through the use of this method. The author has found that a class of 32 iPad lab reports can be graded using the mini-conference system in a typical 50-minute class period.

Why are notebooks, both electronic and nonelectronic, so valuable? One of the most important reasons is that students are able to organize, reflect upon, and retrieve their learning. This enables them to increase their scores assessments and achieve at higher levels. Students tend to have fewer missing assignments, and “no name” papers are a thing of the past. While tablets enable connections to internet research, word-processing capabilities, real-time data, and access to rich video vignettes to expand learning, the composition notebooks have many benefits as well. Composition notebooks are durable. The fact that no pages can be torn out enables students to refer to past results. Any important handouts and foldables can be glued or taped in, and students can incorporate labeled sketches, data tables, predictions, analysis questions, personal reflection, vocabulary, and correction of misconceptions in each lesson. The tablets and composition notebooks are great resources to use at parent/teacher conferences. The evidence to show student learning through investigations is clear. By the time students reach middle school, using hands-on activities to teach meaning in science is critical (NAEP 2013).

Expectations for Each Investigation

Based on a 30-point total, the author uses the following system to grade lab reports.

1. **Title (1 point):** The title should include several descriptive words, not a complete sentence, dealing with the chosen topic of the experiment. It should be brief and catchy, but should also indicate the variable(s) that were tested.
2. **Problem (1 point):** This provides the anticipatory question, which lends focus to learning for the experiment. It should be a complete sentence and phrased as a question. The problem explicitly states the experimental question being investigated, providing enough detail so the audience can understand what will be done.
3. **Prediction (1 point):** The prediction (or hypothesis, depending on the particular requirements in each lab) must be a complete sentence and on-topic. It is not graded for accuracy, but it is often compared and contrasted later with the final outcome of the investigation. This is where the author often targets the correction of misconceptions through class discussion and formative assessment.
4. **Thinking About the Problem (3 points):** This section gives the student necessary background information and content descriptions related to the investigation. The expectation is for the student to develop strengths in literacy by highlighting important sentences while the teacher reads the section out loud. This process helps the student to write three main points from the background information (see Figure I.1, p. XIV for an example). The teacher should have students share several main points out loud, after writing, so that misconceptions can be anticipated and explained.
5. **Labeled Image (3 points):** The image should clearly show the labeled materials and experimental setup, so that the student can describe all procedures. On each lab report, there is a designated space where students can place their image (or draw their sketch, when using composition notebooks). See Figure I.2, p. XV, for an example.

FIGURE I.1.

STUDENT SAMPLE OF "THINKING ABOUT THE PROBLEM" SECTION IN SCIENCE NOTEBOOK

Problem: What is so special about water?
Prediction: Give a working definition of water molecule.
Water Molicules will stick to their Suroundings.

Thinking about the Problem:
What does H_2O mean? Each molecule (*molecula* 'small bit' in Latin) of water is made of two hydrogen atoms (H_2) and one oxygen atom (O). What is special about water molecules is that they tend to "stick" to each other (cohesion) and to other molecules (adhesion). They do this because water is built like a magnet, with a positive end and a negative end. This helps it bond well.

Water makes life on Earth possible. It covers almost three-fourths of the surface of our planet. Because there is so much of it, water may seem very ordinary to us, and yet it is unique when compared to all other substances. For example, water is the only substance on Earth that occurs naturally in all three states-solid, liquid, and gas. In addition, solid H_2O (ice) is less dense than its liquid form (water), so it floats. Most other solids are denser than their liquid form, so they sink! Another difference, with respect to water, is that large amounts of energy must be added to water to achieve even a relatively small change in temperature. That is why our oceans moderate the temperatures of coastal communities on Earth.

Each

Thinking about the Problem:
1. Each Molecule of water is Made of two hydrogen atoms (H^2) and one oxyger atom (O).
2. Water is built like a magnet, with a positive and negative end.
3. water is the only substance on Earth that occures naturally in all three States -Solid, liquid, and gass.

Materials:
8 oz. Drinking Glass
Dish Soap
Eye Dropper
A variety of water containers (assortment of five glasses, buckets, bowls, etc.)
Many Pennies (or replacement item…control for size)
Other Coins

Procedures:
1. Predict which of your five large containers (each full to the rim with water) will be able to withstand the addition of the greatest number of pennies (or replacement item) without spilling over. Test and record your results. Take photos with your iPad while conducting this step.
2. Place a dry penny on a piece of paper towel.
3. Predict the number of drops you can pile on the penny before water runs over the edge.
4. Test and record for each particular coin. Take photos with your iPad during this step.
5. Draw/phtograph and label a sketch/image of the water on the surface of the coin just before the water spilled over.
6. Conduct the same tests with the soapy water.

Analysis:
1. Describe the shape of the water as it "sits" on a coin.

Curved on the penny like a upsidedown U

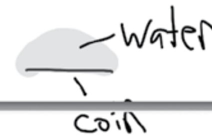


FIGURE I.2.

STUDENT SAMPLE OF LABELED IMAGES IN SCIENCE NOTEBOOK

2. Why does water pile up on a coin, rather than spilling over the edges immediately? How is the soapy water different? (Describe the science behind your thoughts…"Thinking about the Problem" will help you here.)

The water sticks making it curve up and the Soapy water does not stick so it falls of the edge.

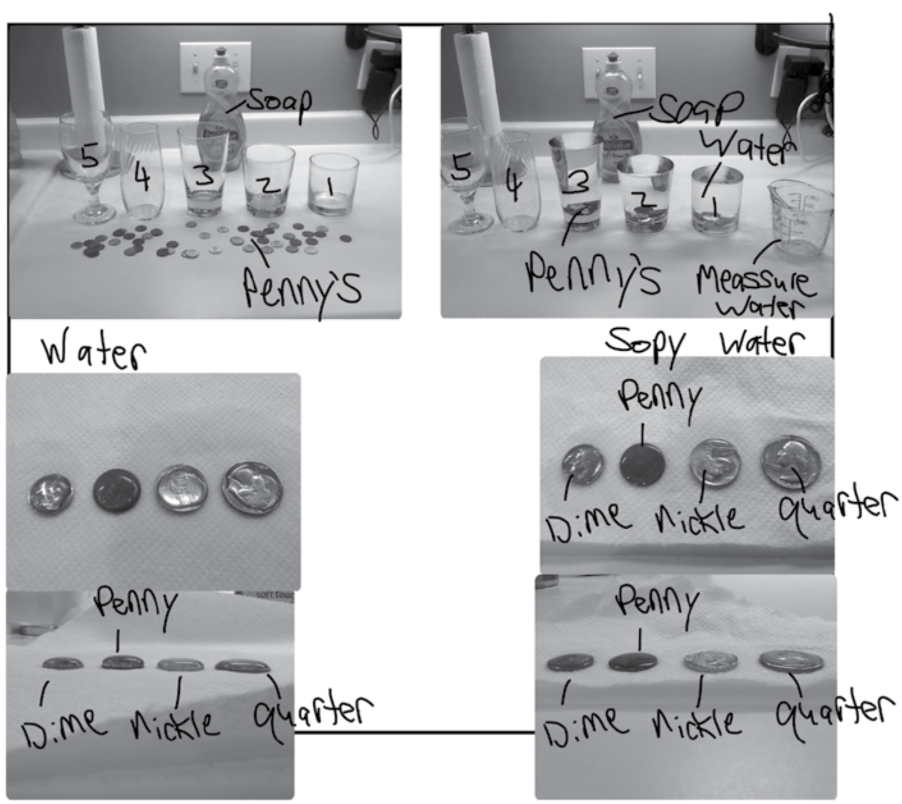
3. Use science concepts to suggest reasons why each of the five containers holds a different number of pennies.

I found out that a glass with a bigger rimb will hold more pennys because their is More surface area/more room for water to bend around rimb.

4. Explain "surface tension" as if you were explaining it to a second grader.

Allows objects like bugs to sit on water.

Labeled Sketches/Images:



6. **Data Tables and Graphs (8 points):** All labs contain at least one data table, and many include graphs, charts, concept maps, and so on. Students are expected to correctly label graphs and tables so the audience can understand them. The evidence presented in the data tables and graphs should be complete and accurate.
7. **Analysis Questions (8 points):** These questions vary in their approaches. Some require students to describe the purpose and procedure for the experiment, while others require a discussion about how variables were controlled. Students will describe what evidence was observed and what was measured, and they will compare the original prediction with the results to help defeat misconceptions. They will also include how the results are supported by other related scientific concepts, research, or theories (using the "Thinking About the Problem" section as a guide). Many analysis questions include internet searches and links to electronic resources and concept maps to promote personal reflection and further the correction of misconceptions. There are also questions for enrichment, which the teacher can use for differentiation. The expectation is that students will answer the analysis questions completely and with accuracy.
8. **Learning Targets (0 points):** This briefly lists a main objective for the lesson or concept learned while conducting the experiment.
9. **"I Learned ..." Statement (1 point):** These are facts and main ideas that apply to what students learned during the investigation. A complete sentence is expected.
10. **"Redo" Statement (1 point):** One of these sentences is due for each investigation. Students must think of a change in the variables (materials or procedures) that might result in a totally new outcome on the lab. An example might be: "I would try the experiment using a black light, rather than sunlight." A good sentence framework to use is, "Instead of using ___, I would use …".
11. **Identify One "Manipulated Variable" (1 point):** A manipulated variable is a particular component of the experiment that is purposefully changed in order to see results. Students should list the main manipulated variable, but do not need a complete sentence.
12. **Identify One "Measured Variable" (1 point):** A measured variable is the evidence of the experiment, which was observed, measured, and recorded

in a data table. Students list one of the measured variables, but do not need a complete sentence.

13. **Identify One "Controlled Variable" (1 point):** A controlled variable is held constant, and it should remain unchanged during the lab. It allows the student to determine what, if any, change took place in their variables during the experiment. Students can list one of the controlled variables, but do not need a complete sentence.

14. **Glossary (0 points):** This is a required section of any notebook, whether or not it is electronic. Definitions of terms can be used as flash card starters, as well. It serves mainly as a study guide and help for analysis and flash card generation but is not a graded portion of each lab report.

15. **Reference Pages (0 points):** These are also a required section of any notebook, whether or not it is electronic. They serve mainly as study guides and help for analysis but are not graded portions of each lab report.

References

During the development and field-testing of both editions of *Earth Science Success*, care was taken to produce a curriculum that would complement well-known Earth science print materials through a research-proven investigation methodology. Among the works consulted, three held the greatest influence: the National Science Teachers Association's four-volume series *Project Earth Science* (Ford and Smith 2000); the two-volume *Hands-on Science* series (Fried and McDonald 2000a, 2000b); and the *Curriculum Research and Development Group* series (Pottenger and Young 1992). Each of these would constitute a valuable resource for teachers who have chosen the lab-centered activities of *Earth Science Success* as their main source of lesson plans and student handouts. Along with the great ideas suggested during field-testing by colleagues, we are also indebted to the National Aeronautics and Space Administration (NASA). Two summers spent at NASA's Space Academy for Educators were instrumental in the original decision to write this book.

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About the Authors

Catherine Oates-Bockenstedt

Catherine has been a teacher of science at the middle-school level for almost 30 years and currently teaches at Central Middle School in Eden Prairie, Minnesota. She received both her BA and MA in science education from the University of Northern Iowa. Certified by the National Board for Professional Teaching Standards (NBPTS) in early adolescent science, she credits the professional development opportunities she has had with NBPTS and with NASA Space Academy for Educators for providing the impetus to write *Earth Science Success*. Wife of Paul, a natural resources biologist, and mother of Lara and Daniel, she lives with her family in Eden Prairie, Minnesota. She is very grateful for the support of her family, friends, and colleagues.

Michael D. Oates

Without the contributions of Michael D. Oates, this book never would have been a possibility. Michael was a professor at both the secondary and university levels for 42 years. Michael received his PhD in French and Linguistics from Georgetown University and is the author of two French textbooks. In 2008, he was decorated by the French government as *Chevalier dans l'ordre des Palmes Académiques*. Invited by his daughter, Catherine, to collaborate on *Earth Science Success*, he became an avid student of science. He was always very grateful for the support of his wife (Catherine's mother), Maureen. Diagnosed with an aggressive form of brain cancer, shortly after seeing *Earth Science Success* become published by the National Science Teachers Association, he passed away in April of 2009.

About These Labs

Each of the labs in every chapter of this book is organized to follow a pattern of active involvement by students. Students are continually presented with searching for evidence using a three-step discovery approach. The three steps are: anticipation, evidence collection, and analysis. *Anticipation* involves reflection on observations and a problem statement, recall of previous knowledge about the topic, discussion of misconceptions, and definition of concepts. *Evidence collection* includes hands-on laboratory investigation techniques. *Analysis* requires confirmation or rejection of results, reporting the findings, and making conclusions about the observations.

The hope is that students will form good habits about testing and controlling all possible variables in their experiments whenever they are collecting evidence. They should be able to identify the manipulated, measured, and controlled variables in each experiment. Results should be reliable and valid. And students should set up controls, as a basis of comparison, so they can determine the actual changes in their data. This pattern of active involvement by students is followed throughout *Earth Science Success*.

Please see the sections found in our introduction for more specifics on successful approaches for each of the labs and lessons, especially "To the Earth Science Teacher" and "Expectations for Each Investigation." In addition, teacher notes are provided to clarify differentiation possibilities, and answers are given whenever the lesson requires one particular response.

4 HISTORY OF PLANET EARTH

4A.

Unearthing History Lab

Problem

Where do life forms appear in a timeline of Earth history?

Prediction

Answer the problem statement.

(*Teacher note:* Have students share several predictions out loud, so misconceptions can be anticipated and explained.)

Thinking About the Problem

How old is Earth? Geologists use information from rocks, rock layers, fossils (*fossus* "dug up" in Latin), and other natural evidence to piece together the history of our planet. Geologists consider time from the formation of the Earth to today, following a geologic timescale that breaks Earth's history into manageable pieces. Geologic time is divided and subdivided into eons, eras, periods, epochs, and ages. They have used this information to put geologic events and fossil organisms (evidence of living things) in their correct sequence on this timeline. The boundaries are set by major events that have been preserved in the rock record.

More recent events can be measured in the soil, as well. For example, Earth systems scientists now believe that an early culture of humans, known as the Clovis people, wandered North America, hunting mammoths and sloths. Their culture came to an end when a mile-wide comet wiped them out. Scientists believe this due to evidence found in a thin layer of black soil, containing iridium from comets, which coats more than 50 sites in North America, especially near the Great Lakes.

Through research, including the use of the geologic time scale, most scientists conclude that Earth is approximately 4.6 billion years old. You will learn more about what evidence scientists use to determine this age in our next lab. Compared to 4.6 billion years, living things have been around for a relatively short time. This lab will help you learn about the geologic timeline for the Earth and more clearly understand the various geological periods and events you will hear described in the media.

Materials

- Earth History on a Rope Scale Model Measurements
- Masking tape
- Rope or twine (5 meters long)
- Ruler
- Scrap paper for labels

Procedure

1. Lay the rope out on the ground in front of you. At the far right end, tape the label "Present Day."
2. Starting from the "Present Day" mark, measure back exactly 4.6 meters. Label this "Formation of the Earth."
3. Measure from the Present Day mark, using Data Table 4.1 (p. 157), and label each eon, era, period, and epoch (with a different color code).
4. Use Data Table 4.2 (p. 158) to label each event in Earth's history.

(*Teacher note:* This is treated as a presentation of "Earth History on a Rope" for Enriched Science, and an "Earth History Timeline" for Regular Science—using a 46 cm line drawn on paper. The four sample analysis questions are for "practice" to prepare for their two presentation questions in front of their peers. As a small group, students work on the rope timeline and you spot-check three particular measurements. If the students are within 2 cm of actual, then they get full credit for the rope timeline. If they are not, then they each lose 2 points for each incorrect measurement (out of 30 points total). Then, for individual accountability, each student has to answer two questions from the list on this document. Each question costs them 2 points per wrong answer. This means that the lowest score any student will receive, should they work in a group on the rope timeline, is 20 out of 30. Data tables include information pertinent to the state of Minnesota.)

Sample Analysis

1. Hypothesize how the geologists divided the time scale into smaller units.
2. Where on the timeline are the two major extinction events?

3. The time from 4.6 billion years ago up until the beginning of the Phanerozoic eon is called Precambrian Time. Find this part of your timeline. How does Precambrian Time compare in length with the rest of the geologic time scale?
4. The Cenozoic era is the most recent era, and it includes the present. How does the Cenozoic era compare in length with the other eras?

Geologic Timescale Presentation Questions

Make questions #1 and #26 available to prepare students, while they get their rope timelines and are waiting to be called on. (*Teacher note:* Answers are given in parentheses.)

1. How many points, or lengths from present day, are marked with events or dates on your rope? (46)
2. Name the eras that are marked on your rope. (Paleozoic, Mesozoic, Cenozoic)
3. Describe what the color code is for the five colors that you used. (Need five colors: eons, eras, periods, epochs, and fossil/events)
4. The time on your geologic time scale from 4.6 billion years ago up until the Phanerozoic eon is called Precambrian time. How does the length of the Precambrian time compare to the rest of the scale? (Precambrian is longer.)
5. The Cambrian period marks the beginning of the complex life forms (like trilobites) in Earth history. How does the length of the Cambrian to present compare with the length of the rest of the geologic time scale? (Cambrian is shorter.)
6. When on the timeline are the two major extinction events? (248 million years ago and 65 million years ago)
7. Hypothesize or explain how you think geologists divided the time scale into smaller units. (Based on life forms found in each unit)
8. Which came first, the Rocky Mountains or the dinosaur extinction? (Rocky Mountains)
9. Which came first, the mammals or the reptiles? (Reptiles)
10. Which came first, the mammals or the flowering plants? (Mammals)
11. Which came first, the amphibians or the reptiles? (Amphibians)

12. Which came first, the flowering plants or the dinosaur extinction? (Flowering plants)

13. Which came first, the Rocky Mountains or the continental ice age being over? (Rockies)

14. Which came first, the green algae or the trilobites? (Green algae)

15. Which came first, the amphibians or the trilobites? (Trilobites)

16. Which era lasted longer, Paleozoic or Mesozoic? (Paleozoic)

17. Give a good Redo Statement for this lab.

18. The Archean eon marks the beginning of the simple life forms (like bacteria) in Earth history. How does the length of the Archean to the beginning of the Cambrian period compare with the length of the Cambrian period to present day? (Archaen to Cambrian is longer.)

19. The Proterozoic eon marks the halfway point for Earth's history. How does the length of the Proterozoic to Cambrian compare with the length of the Cambrian to present day? (Proterozoic to Cambrian is longer.)

20. Which came first, the extinction of dinosaurs or the greatest mass extinction? (greatest mass extinction)

21. Which came first, the mammals or the greatest mass extinction? (Greatest mass extinction)

22. Which came first, the continental ice age or the modern humans? (Modern Humans)

23. Which came first, the Carboniferous period or the reptiles? (Carboniferous)

24. Which came first, the Ordovician period or the first trilobite? (Trilobite)

25. Which came first, the Cenozoic era or the extinction of the dinosaurs? (They're both the same date)

26. Why is the following phrase significant? Pregnant camels often sit down carefully. Perhaps their joints creak… though possibly they're not quick. (First letter of all periods.)

27. Which came first, the Paleozoic era or the Mesozoic era? (Paleozoic)

28. Which period lasted longer, Cambrian or Ordovician? (Cambrian)

29. Which came first, the Carboniferous period or the Silurian period? (Silurian)

30. Which came first, the Milocene epoch or the Eocene epoch? (Eocene)

31. Which lasted longer, the Jurassic period or the Cretaceous period? (Cretaceous)
32. Which Precambrian eon lasted longer, the Priscoan or Archean? (Archean)
33. Which came first, the Triassic period or the Tertiary Paloegene period? (Triassic)
34. Which lasted longer, the Ordovician period or the Silurian period? (Ordovician)
35. During which period are trilobites first found? (Cambrian)
36. During which period were the first mammals found? (Triassic)
37. During which period were the first flowering plants found? (Cretaceous)
38. During which period did the Rocky Mountains begin to rise? (Cretaceous)
39. During which period were the first amphibians found? (Devonian)
40. During which epoch were modern humans first found? (Pleistocene)
41. What event marks the beginning of all of the epochs? (The extinction of the dinosaurs)
42. During which period were the first reptiles found? (Carboniferous)
43. During which eon were the first green algae found? (Precambrian Proterozoic)
44. Which came first, the Ordovician period or the Quaternary period? (Ordovician)
45. Which came first, the Permian period or the Cenozoic era? (Permian)
46. Which eon came first, the Precambrian Priscoan or the Precambrian Archean? (Priscoan)
47. Which came first, the Eocene epoch or the Pliocene epoch? (Eocene)
48. Which Epoch lasted longer, the Oligocene or the Miocene? (Miocene)
49. Which came first, the Carboniferous period or the Permian period? (Carboniferous)
50. Which came first, the continental ice age or the start of the Pleistocene epoch? (Pleistocene)
51. Which epoch lasted longer, the Pliocene or the Miocene? (Miocene)
52. Which era lasted longer, the Mesozoic or the Cenozoic? (Mesozoic)

53. Which event came first, the first green algae or the first bacteria? (Bacteria)
54. Which event came first, the rise of the Rocky Mountains or the first mammal? (Mammal)
55. Which period lasted longer, the Devonian or the Triassic? (Devonian)
56. Which eon lasted longer, the Precambrian Priscoan or the Precambrian Archean? (Archean)
57. Which came first, the Silurian period or the first amphibian? (Silurian)
58. Which period lasted longer, the Tertiary Neogene or the Quaternary? (Tertiary Neogene)
59. Which came first, the Holocene epoch or the end of the continental ice age? (Holocene)
60. Which eon came first, the Precambrian Priscoan or the Precambrian Archean? (Precambrian Priscoan)
61. Which came first, the rocks in Lac Qui Parle, Minnesota, or the rocks in Taylor’s Falls, Minnesota? (Lac Qui Parle)
62. Which came first, the inland sea or the glaciers covering Minnesota? (Inland sea)
63. Which came first, the glaciers or the humans? (humans)
64. Which came first, the glaciers or the Minnesota River Valley? (glaciers)
65. Which event came first, the inland sea in Minnesota or the flowering plants? (inland sea)
66. During which eon were the gneiss rocks formed in Lac Qui Parle State Park, Minnesota? (Precambrian Archean)
67. During which period was Minnesota covered by inland seas? (Jurassic)
68. During which period did the Superior Lobe and Des Moines Lobe Glaciers leave deposits in Minnesota? (Quaternary)
69. How would the rope timeline compare in length with one created for Mars? (Both ropes would be the same length)
70. How would the rope timeline compare in length with one for the Moon? (Both ropes would be the same length)

DATA TABLE 4.1.

EARTH HISTORY

GEOLOGISTS' DIVISION OF EARTH HISTORY	HOW MANY MILLIONS OF YEARS AGO IT BEGAN	MEASUREMENT ON ROPE (0.1 CM = 1 MILLION YEARS)
Chronometric Eons		
Precambrian Priscoan	4600	460.0 cm
Precambrian Archean	3800	
Precambrian Proterozoic	2500	
Phanerozoic	544	
Eras		
Paleozoic	544	54.4 cm
Mesozoic	248	
Cenozoic	65	
Periods		
Cambrian	544	
Ordovician	490	49.0 cm
Silurian	443	
Devonian	417	
Carboniferous	354	
Permian	290	
Triassic	248	
Jurassic	206	
Cretaceous	144	
Tertiary Paleogene	65	
Tertiary Neogene	24	
Quaternary	2	
Epochs		
Paleocene	65	6.5 cm
Eocene	55	
Oligocene	34	
Miocene	24	
Pliocene	5	
Pleistocene	2	
Holocene	0.01	

DATA TABLE 4.2.

EVENTS IN EARTH'S HISTORY

EVENTS	TIME (MILLIONS OF YEARS AGO)
Continental ice age is over in United States	0.001
Glacial river Warren carves out the Minnesota River Valley	0.0012
Superior Lobe and Des Moines Lobe Glaciers leave deposits in Minnesota	0.002
Modern humans	0.5
Early humans	2
Extinction of dinosaurs	65
Rocky Mountains begin to rise	80
Flowering plants	130
Twin Cities are covered by seas	150
First mammal	210
Greatest mass extinction	248
First reptiles	315
First amphibians	367
Inland Sea covers Minnesota	480
Minnesota is positioned over the equator	300
First trilobite	554
First green algae	1000
Basalt rocks formed in Taylor's Falls, Minnesota	1100
Gneiss rocks formed in Lac Qui Parle State Park, Minnesota	3600
First bacteria	3800

4A. Unearthing History Lab

NGSS Alignment

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.

MS-ESS2-3. Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.

4B.

Drilling Through the Ages Lab

Problem

How can we use drilling for wells as a way to understand geologic history?

Prediction

What methods can be used to determine the ages of rock layers?

(*Teacher note:* Have students share several predictions out loud, so misconceptions can be anticipated and explained.)

Thinking About the Problem

Why are geologists interested in drilling? Geologists work together with engineers when drilling for groundwater wells. Drilling allows geologists to examine where different layers of rock begin and end. In the search for water, geologists frequently look for a layer of sandstone perched above a layer of impermeable shale.

Geologists also have an interest in drilling because rock layers provide a record of events that have occurred on Earth. They can contain the remains and imprints of the different plants and animals that have lived on Earth. There are many deep wells (water, oil, and so on) available for geologists to examine.

Scientists estimate that Earth is approximately 4.6 billion years old. There are many pieces of supporting evidence for this. One piece of supporting evidence is the thickness of the rock layers on Earth. Scientists can perform experiments to determine how long it takes to create one meter of a particular rock type. They then multiply this time by the actual thickness of those particular rock layers on Earth. This allows scientists to roughly estimate the age of the Earth. Most geologists believe that it would have taken approximately 4.6 billion years to generate all the layers of rock found on Earth. This study of rock layer depths has been backed up by much more accurate evidence from radioactive minerals and index fossils in the rocks.

Earth scientists study the evidence associated with when the continents began to solidify. Newly discovered Greenland outcrops (an ancient piece of the sea floor, which was raised up by crustal movement) are among the oldest measured, at 3.8

billion years, while most of the continents are much younger, at 2.5 billion years old.

By understanding some simple rules about rock layer formation, we can use the layers and the associated rock types to measure the amount of time that has passed. One important thing to remember is that rock layers form horizontally. A second important factor is that the older rocks will normally be found farther beneath the surface, while younger rocks will normally be closer to the top. This allows scientists to use the positions underground to determine the "age based on position."

Scientists can use index fossils to determine the "relative age" of layers. Index fossils are the remains of a single species that are so widespread and well known (age-wise), that its fossils enable geologists to correlate environments and time. They can also measure the radioactive minerals found in a rock layer to determine the "absolute age" of the layer.

Write three main points from the "Thinking About the Problem" reading:

1.

2.

3.

Procedure

1. At each drilling site on Figure 4.1 (p. 163), place a small horizontal line at the depths described in Data Table 4.3 (p. 162). Write the name of the rock on that line. The first line for Water Well C, sandstone, has been done for you.
2. Draw a line across the page to connect the areas on all three wells where the rock layers are the same.
3. Use the notes from Data Table 4.3 to determine the age of each rock layer. Write the age in parentheses to the right of the rock layer name.
4. Complete Data Table 4.4 (p. 164) in order from youngest (1) to oldest (11).

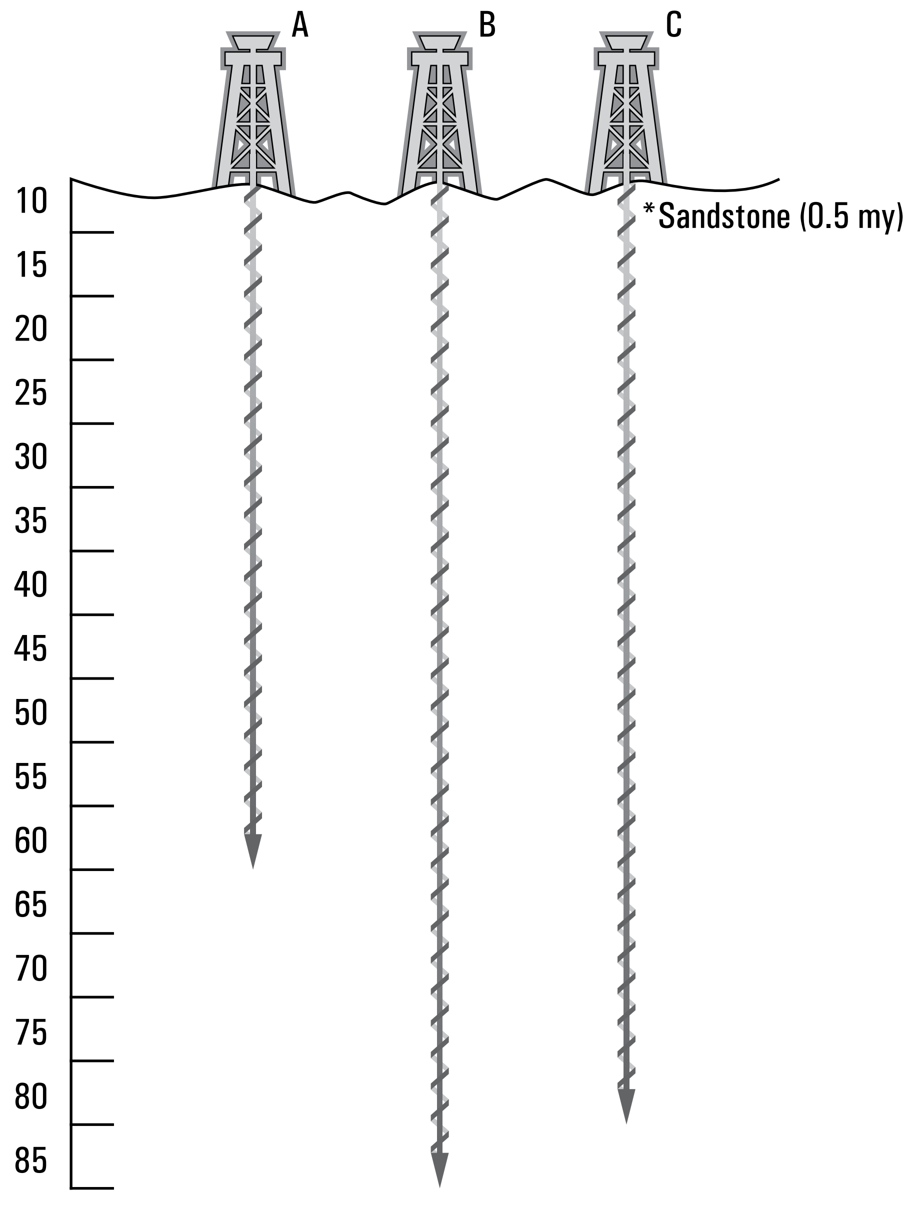
DATA TABLE 4.3.

INFORMATION FROM WATER WELLS A, B, AND C

WATER WELL A		
DEPTH (M)	**ROCK**	**GEOLOGIST NOTES**
12	Shale	
16	Conglomerate	
25	Sandstone	135 million years old (Index fossils found)
30	Impermeable Shale	No Date Available
45	Breccia	
53	Sandstone	
58	Shale	
WATER WELL B		
DEPTH (M)	**ROCK**	**GEOLOGIST NOTES**
15	Shale	21 million years old (Index fossils found)
16	Conglomerate	
23	Sandstone	
26	Impermeable Shale	
45	Breccia	
51	Sandstone	280 million years old (Radioactive dating)
60	Shale	310 million years old (Index fossils found)
70	Schist	385 million years old (Radioactive dating)
76	Marble	
85	Basalt	
WATER WELL C		
DEPTH (M)	**ROCK**	**GEOLOGIST NOTES**
5	Sandstone	0.5 million years old (Radioactive dating)
18	Shale	
21	Conglomerate	51 million years old (Index fossils found)
25	Sandstone	
34	Impermeable Shale	
47	Breccia	230 million years old (Index fossils found)
55	Sandstone	
63	Shale	
70	Schist	
75	Marble	405 million years old (Radioactive dating)
81	Basalt	460 million years old (Radioactive dating)

FIGURE 4.1.

DRILLING THROUGH THE AGES DIAGRAM



DATA TABLE 4.4.

AGES OF EACH ROCK LAYER

NUMBER OF ROCK LAYER	ERA	PERIOD	AGE OF ROCK LAYER	METHOD USED TO DETERMINE AGE	TYPE OF ROCK
1	Cenozoic	Quaternary	0.5 million years	Radioactive	Sandstone
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					

DATA TABLE 4.5.

GEOLOGIC TIME TABLE

MILLIONS OF YEARS AGO	ERA	PERIOD
0–2	Cenozoic	Quaternary
2–24	Cenozoic	Tertiary Neogene
24–65	Cenozoic	Tertiary Paleogene
65–141	Mesozoic	Cretaceous
141–195	Mesozoic	Jurassic
195–230	Mesozoic	Triassic
230–280	Paleozoic	Permian
280–310	Paleozoic	Pennsylvanian
310–345	Paleozoic	Mississippian
345–395	Paleozoic	Devonian
395–435	Paleozoic	Silurian
435–500	Paleozoic	Ordovician
500–570	Paleozoic	Cambrian

Analysis

1. Explain one other way to find out the age of the rock in layer #5.
2. Explain whether or not all of the similar rock types are found at the same depth.
3. Describe the difference between the relative age of a rock layer and its absolute age.
4. (Enrichment) What type of evidence would be found in the rock layers if there had been volcanic eruptions in the past?
5. (Enrichment) Construct a scientific explanation about how you would use evidence found in rock layers, in order to prove that volcanic eruptions had happened in the past.
6. (Enrichment) Contact a local water, oil, or gas drilling company to discover and learn from their methods of collecting evidence on the rock layers underground in our community. Create an iMovie trailer to share with the class to teach them what you've learned.

Learning Target

Use the rock layers and the associated rock types to measure the amount of time that has passed.

I Learned:

Redo:

Manipulated Variable:

Measured Variable:

Controlled Variable:

4B. Drilling Through the Ages Lab

NGSS Alignment

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.

MS-ESS2-1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.

MS-ESS2-3. Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.

4-ESS1-1. Identify evidence from patterns in rock formations and fossils in rock layers for changes in a landscape over time to support an explanation for changes in a landscape over time.

4C.

Decaying Candy Lab

Problem

How many half-lives will it take for a sample of candy to decay?

Prediction

Give a working definition of "half-life."

(*Teacher note:* Have students share several predictions out loud, so misconceptions can be anticipated and explained.)

Thinking About the Problem

When are rocks born? How do we know what their birthdays are? For igneous rocks, that birthday is when they first harden from magma or lava to become rock. All of the elements within an igneous rock help us to identify it. Most elements within the rock are stable and remain the same through the years. Some, however, are unstable. Over time, these elements decay, or break down, changing into new elements by releasing energy and subatomic particles. This process is called radioactive decay. Radioactive elements, such as uranium and radon, occur naturally in igneous rocks.

Unstable elements are said to be radioactive. During radioactive decay, the atoms of one element break down to form atoms of another element. As a radioactive element within the igneous rock decays, it changes into another element. So the composition of the rock changes slowly over time. The amount of the radioactive element decreases, while the amount of the newly formed element increases.

The particular rate of decay for each radioactive element never changes, and is referred to as the half-life. The half-life measures how long it takes for any quantity of radioactive elements within the rock to decay by half. Geologists use the rate at which these elements decay to calculate the rock's age. They can use radioactive dating to determine what is called the absolute age, or the birthday, of rocks.

As all plants and animals grow and travel through their lives, carbon atoms are added to their tissues. There is a radioactive form of carbon called carbon-14.

All living things contain carbon atoms, including some carbon-14. It has a shorter half-life (5,730 years) than the elements found in igneous rocks, and can be used to determine the age of some living things. After an organism dies, no more carbon is added to the tissues. But since the carbon-14 in the organism's body is radioactive, it decays. It breaks down into a stable nitrogen-14 atom. To determine the age of a once-living thing, scientists measure the amount of carbon-14 that is left in the living thing's remains. From this amount, they can determine the absolute age, or years that have passed since its birthday. Carbon-14 has been used to determine the age of frozen mammoths and prehistoric humans.

Write three main points from the "Thinking About the Problem" reading:

1. Geologists use radioactive dating to ...

2.

3.

Procedure

1. Place 50 "atoms" of candy (M&Ms) in the cup, and gently shake for 10 seconds, representing its half-life.
2. Gently pour out candy. Count the number of pieces with the M&M side up. These atoms have "decayed." Record amount in Data Table 4.6.
3. Return only the pieces with the print-side down to the cup. You may consume the "decayed' (print-side up) atoms.
4. Continue gentle 10-second shaking, counting, and consuming until all the atoms have decayed. Draw a sketch of you materials in box on p. 169.
5. Combine all of the class data, and graph the whole-class average data (Data Table 4.7).
6. In Figure 4.2 (p. 171), label time (seconds) on the *x*-axis. Label the number of undecayed atoms on the *y*-axis. Give your line graph a descriptive title.

INSERT LABELED SKETCH OF EXPERIMENTAL MATERIALS HERE.

DATA TABLE 4.6.

SMALL-GROUP DATA

HALF-LIFE (SECONDS)	# OF UNDECAYED ATOMS (RUNNING TOTAL)	# OF DECAYED ATOMS (RUNNING TOTAL)
0	50	0
10		
20		
30		
40		
50		
60		
70		
80		

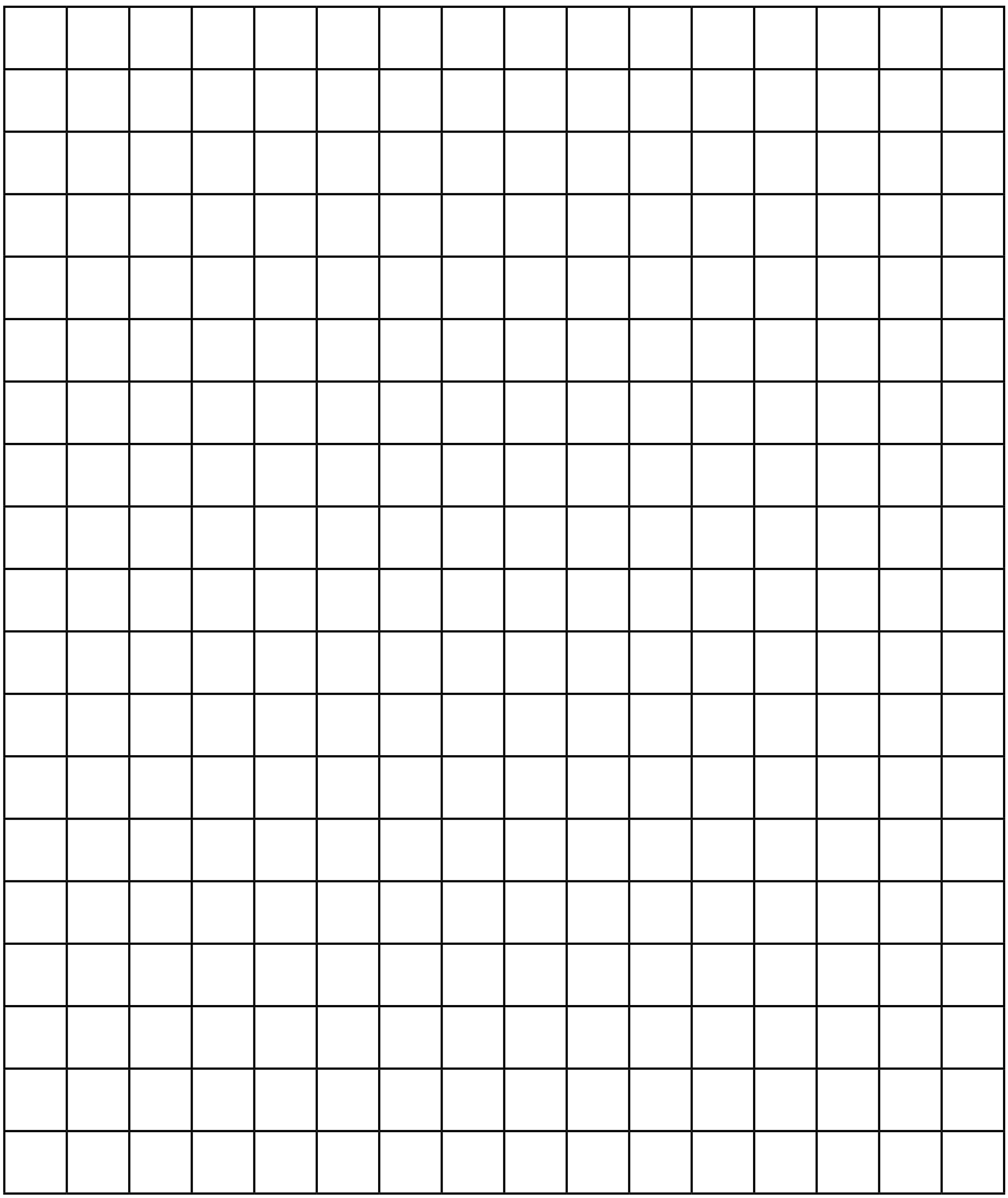
DATA TABLE 4.7.

WHOLE CLASS-DATA ON UNDECAYED ATOMS

HALF-LIFE (SEC)	0	10	20	30	40	50	60	70	80
Group 1	50								
Group 2	50								
Group 3	50								
Group 4	50								
Group 5	50								
Group 6	50								
Group 7	50								
Average	50								

FIGURE 4.2. ______________________________

(*Teacher note:* Student provides descriptive graph title.)



Three Graphing Hints for Students

1. Read Procedure #6 again.
2. Use the full graph—it should be a big picture of important data. Count by an appropriate number.
3. Use the line on your graph to determine what the half-life of the candy sample is, in seconds.

Analysis

1. Give a working definition of half-life.
2. In the experiment, what was the half-life of the candy sample?
3. At the end of two half-lives what fraction (or percent) of the atoms had not decayed?
4. (Enrichment) How good is our assumption that half of the candy atoms will decay in each half-life? Explain.
5. (Enrichment) Is there any way to predict when a particular atom of candy will decay? (If you could follow the fate of one M&M, is there any way to predict exactly when it will "decay?") Explain.
6. Describe the shape of the curve drawn in on your graph of the class data.
7. Why did we combine to get the whole-class data? How does this relate to radioactive dating?
8. If you started with a sample of 600 atoms of candy, how many would remain undecayed after three half-lives?
9. (Enrichment) If 175 undecayed nuclei remain from a sample of 2,800 nuclei, how many half-lives have passed?
10. (Enrichment) The element Strontium-90 has a half-life of 28.8 years. If you start with a 10 g sample of Strontium-90, how much will remain after 115.2 years? Show your math.

Learning Target

Use the radioactive half-life of elements to determine a sample's absolute age.

I Learned:

Redo:

Manipulated Variable:

Measured Variable:

Controlled Variable:

4C. Decaying Candy Lab

NGSS Alignment

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.

MS-ESS2-3. Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.

MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.

Index

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

Q

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