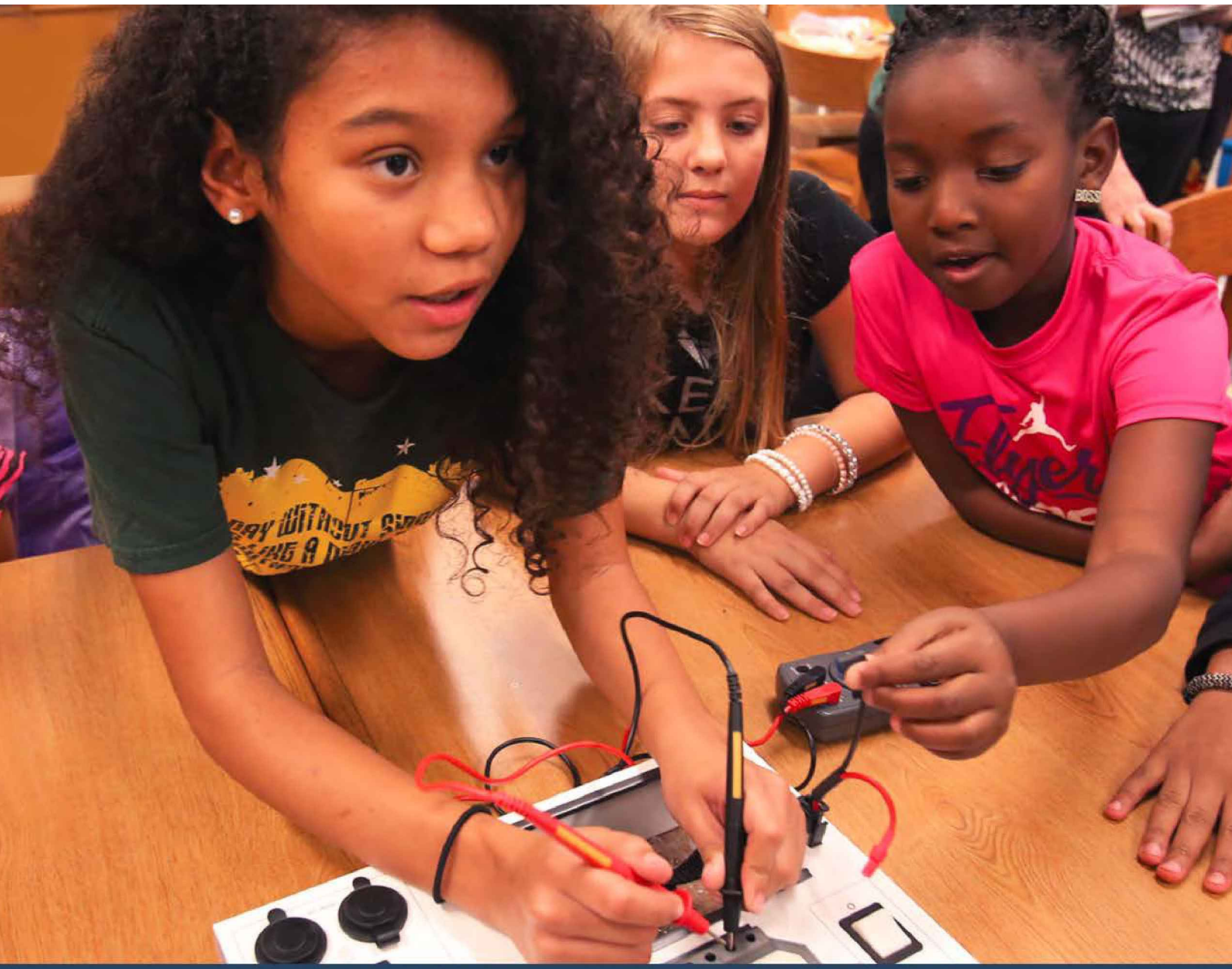

JANICE KOCH

SCIENCE STORIES

6th Edition

Science Methods for Elementary and Middle School Teachers

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Sixth Edition

SCIENCE STORIES

Science Methods for Elementary and Middle School Teachers

Janice Koch

Emeritus, Hofstra University

CENGAGE Learning

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In memory of Beatrice Deutsch

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Preface

For the elementary or middle school teacher, teaching science is frequently a challenging task, and sometimes it can even be intimidating. This book is an invitation to elementary and middle school science. It is a welcome mat for future teachers, inviting them to the world of science and inspiring them to teach it.

I have written this book so that it can be used as a core text in a science methods course for preservice or in-service teachers. But its approach and content are forged from my own struggles to find material that addresses the school science experience as a natural part of the classroom's daily life. Because many future teachers are apprehensive about teaching science, it is important to help them believe in themselves as science learners and to see themselves as scientific. What does it mean to work like a scientist? Or to think scientifically? Often, like many others in our society, they have a culturally constructed stereotype of the scientist: a kind of mad genius in a white lab coat who does strange, inexplicable things with test tubes. Unfortunately, many conventional texts do little to counter these preconceptions, and when teachers begin to work with students, they often convey the same apprehension and the same brand of stereotype. This book attempts to break the cycle by showing teachers that they do indeed have a "scientist within." By discovering their own scientific selves, teachers can reawaken the joy and wonder of unraveling the mysteries of the natural world, and they can share that experience with their students.

New Features in the Sixth Edition

Since the last edition of *Science Stories* went to press, new national science standards for K–12 science teaching have been developed, offering a three-pronged approach to teaching science. The three dimensions to the Next Generation Science Standards are: (1) science and engineering practices, (2) disciplinary core ideas in life, physical, earth, and space sciences and engineering technology and applications of science, and (3) crosscutting concepts. The first step in developing the new standards was *A Framework for K–12 Science Education* developed by the National Research Council (2012). This document laid out the three dimensions of science education that were the basis for the NGSS (2013). These standards are described and referred to throughout the sixth edition of *Science Stories*. A major goal of sixth edition is to bring these standards to life.

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Building on the fifth edition, this edition of *Science Stories* continues to suggest ways to take the students outside and further their understanding and appreciation of nature. At the same time exponential technological growth and an explosion of knowledge in the fields of neuroscience, nanotechnology, and environmental science contribute to the stories in this text. Emphasizing science and engineering practices and not solely science process skills is a major contribution of this sixth edition, while engineering design challenges are a significant feature of *Science Stories*. As our students rely on social media and on their devices for much of their information, there is a flood of data that needs to be vetted. What counts for evidence in making statements about the natural world? What are the data behind global climate change? What can be learned by gathering evidence from events in nature? Watching my own granddaughters grow in this age of instant communication and access to data reminds me that the simple joy of exploring a bird's nest is more important than ever.

The following **new features** are found in this sixth edition:

- New stories of teachers and students working inside and outside the classroom, bringing the STEM education movement to life as they integrate science, technology, engineering, and mathematics.
- Stories that connect literature, poetry, and the visual and performing arts to scientific understandings, adding to the STEAM education movement, where the "A" stands for the arts.
- Included in this edition is an entirely new chapter devoted to science stories of an interdisciplinary nature, integrating scientific understandings with language arts, mathematics, art history, and engineering design.
- This edition continues to emphasize the importance of **engineering design** as a way to apply what students learn in science to the design and construction of models and artifacts. This edition expands on what we know about how people learn. It stresses the importance of **disciplinary core ideas,** what I used to refer to as **"big ideas,"** and how these enduring understandings can be revealed when teachers and students "unpack" those concepts together. It also emphasizes how the science concepts progress to deeper levels as the students mature. Examples of these **learning progressions** are embedded in the text and become explicit in Chapter 7.
- Throughout the book, you will see students accessing the Internet to communicate, gain information, and check for understanding. You will find students actively engaged with social media, online simulations, and blogs set up by their teachers. Yet this edition, like earlier ones, continues to present technology not as an end in itself but as a tool to help students engage in learning projects and construct their own knowledge.
- Chapter 11, "Surrounded by Science: Science Connections across Disciplines," continues to focus on interdisciplinary connections—offering guidance on how to use poetry, literature, social studies, engineering design, and works of art to teach science.

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- *The sixth edition of* Science Stories *answers these questions:* How can I do this? Where do I start? How do I use the new standards? What does a successful science lesson look like?
- This edition also contains a comprehensive chapter on life science, physical science, and earth and space science disciplinary core ideas as well as a chapter considering student assessment and, finally, self-assessment.

Chapter-by-Chapter Overview

Chapter 1

In Chapter 1, we introduce the reader to the many ways we can think about science and scientists and to the thinking behind *The Next Generation Science Standards.* This chapter combines the first two chapters from the fifth edition of *Science Stories* and invites the reader to think about their personal experiences with learning science and what steps they may take to becoming invested in their own science learning. Chapter 1 foreshadows the stories of teachers and students doing science together by highlighting what the reader should be looking for. It is here that students are introduced to locating their own inner scientist.

Chapter 2

In this edition, Chapter 2 introduces the reader to what it looks like when teachers and students are engaged in doing science together and expands upon the science stories' meaning by introducing the science concepts and teaching ideas behind each story and how they are connected to the NGSS. Addressing how people learn by constructing meaning from their experiences is key to Chapter 2.

Chapter 3

In Chapter 3 we revisit the science circus from earlier editions, relating the stations to science and engineering practices.

Chapter 4

This chapter takes students outdoors and introduces new stories of doing science with students both inside and outside of the classroom.

Chapter 5

This chapter revisits what it means to get messy in science and how that messiness comes from the investigations and, sometimes, resides in the categories we use to classify matter! In this edition, the reader explores what it would take to teach these messy science lessons themselves. In a new story, third-grade students struggle with how to describe properties of solids, liquids, and gases.

Chapter 6

Extended investigations of living things is a major theme of this chapter, and connections to the NGSS offer insights into the crosscutting concept of structure and function. Living things remain a fascination for all students, especially those in elementary and middle school.

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Chapter 7

This chapter brings a learning progression to life as students learn about the mass, volume, and density of materials and different ages and stages of development. We meet the first engineering design challenge of the sixth edition in this chapter.

Chapter 8

In this chapter, we update the former Chapter 9 from the fifth edition. We examine engineering practices in the classroom. A practical part of engineering education, the design challenge asks students to design and construct a solution to a problem using what they have learned about the core concept. This application of knowledge is revealed in Chapter 8 by examining the design and construction of atomic models.

Chapter 9

In this chapter, we problematize the "science kit," reminding the reader that science investigations need to give students the opportunity to plan investigations and argue from evidence. Once again, this sixth edition includes asking the reader questions that will help them find a way to teach this unit themselves.

Chapter 10

Chapter 10 examines basic science content for life, physical, and earth sciences while introducing the reader to the current thinking behind STEM education. This is an excellent lead-in to a more interdisciplinary approach to teaching science that is explored in the new Chapter 11 of the sixth edition.

Chapter 11

Whether it is writing dialog poems, essays, personal letters, or journal entries, writing is a significant part of expressing and communicating science concepts. Some students use artistic devices to express meaning, while others use engineering design or concept maps. This interdisciplinary chapter places science in the center of the elementary and middle school curriculum. The stories are authentic and serve as a reminder that, indeed, we are surrounded by science and that science connections to other disciplines are not hard to find.

Chapter 12

Planning for teaching science is key to a successful lesson. This revised chapter helps the reader to examine what is required to plan and implement a successful K–8 science lesson that is aligned with the NGSS. This edition continues to address the needs of underrepresented groups in science.

Chapter 13

This revised assessment chapter addresses the importance of assessment being a good instructional task and the need for assessment to match instruction. Examples throughout this chapter represent authentic assessment techniques.

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Chapter 14

In this final chapter, the emphasis is on metacognition and self-assessment. It offers advice to future teachers as they plan for and implement science investigations throughout elementary and middle school.

Science Stories: Narrative as a Tool for Science Teaching and Learning

Those who are new to this book may wonder, "Why does it tell so many stories?" Thirty years ago, when I began to teach the science methods course at a major metropolitan university, I started telling stories about my own experiences doing science with children. I found that the stories helped my students understand both what science is and how they could facilitate science experiences in their own classrooms.

At about the same time, I was traveling to various school districts to help teachers create science experiences in their classrooms. I spent many months visiting schools and modeling science lessons. As I learned a great deal from the students and their teachers, I realized that their stories had important implications for my teacher education classes. Thus my repertoire of stories naturally expanded. Today, they continue to expand as I work on funded projects to improve science education.

The use of narrative is not new to teacher education, but it is a fresh approach to the science methods course. This book presents much of its theory and its practical advice by way of stories about students and teachers actually doing science together. Rather than imbibing generalities out of context, readers can see what the principles mean in typical classroom situations. This edition connects the NGSS to these stories.

How Do the Science Stories Work?

The stories are set in a framework of discussion that helps readers to see the larger picture. Following each story or set of stories, four sections draw out the implications of the narrative and stimulate reflection.

1. *The Teaching Ideas behind This Story.* A discussion of the science teaching ideas that are demonstrated by the science story. In this section the reader comes to understand the reasoning behind the techniques modeled by the teacher in the story.
2. *The Science Ideas behind This Story.* An explanation of specific science concepts that the reader should understand in order to grasp the science story fully.
3. *Connections to the Next Generation Science Standards.* A description of which NGSS disciplinary core ideas, crosscutting concepts, and science and engineering practices are illustrated.
4. *Exploring Further.* Questions that prepare readers to implement the lessons in their own classrooms.

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Other Learning Features of This Text

In addition to the science stories, the vital theoretical background, and the frequent links to national standards, this book provides readers with important tools to help them use the material effectively. These tools include:

- **To Think About.** At the beginning of each chapter, the reader is asked to reflect on a few key questions. These try to make a personal connection to the reader in a way that invites thought about the chapter topics.
- **Marginal Glossary.** The glossary in the margins provides clear, concise definitions of key scientific and pedagogical concepts. The full glossary is provided at the end of the book for a complete listing.
- **Science Concepts.** The Science Concepts box highlights key science concepts, facilitating learning and review.
- **MindTap for Education.** MindTap is a first-of-its kind digital solution with an integrated eportfolio that prepares teachers by providing them with the knowledge, skills, and competencies they must demonstrate to earn an education degree and state licensure and to begin a successful career. Through activities based on real-life teaching situations, MindTap elevates students' thinking by giving them experiences in applying concepts, practicing skills, and evaluating decisions, guiding them to become reflective educators.

Accompanying Teaching and Learning Resources

This sixth edition of *Science Stories* is accompanied by an extensive package of instructor and student resources.

MindTap™: The Personal Learning Experience

MindTap for Koch, *Science Stories*, 6e, represents a new approach to teaching and learning. A highly personalized, fully customizable learning platform with an integrated eportfolio, MindTap helps students to elevate thinking by guiding them to:

- Know, remember, and understand concepts critical to becoming a great teacher.
- Apply concepts, create curriculum and tools, and demonstrate performance and competency in key areas in the course, including national and state education standards.
- Prepare artifacts for the portfolio and eventual state licensure to launch a successful teaching career.
- Develop the habits to become a reflective practitioner.

As students move through each chapter's Learning Path, they engage in a scaffolded learning experience, designed to move them up Bloom's Taxonomy, from lower- to higher-order thinking skills. The Learning Path enables preservice students to develop these skills and gain confidence by:

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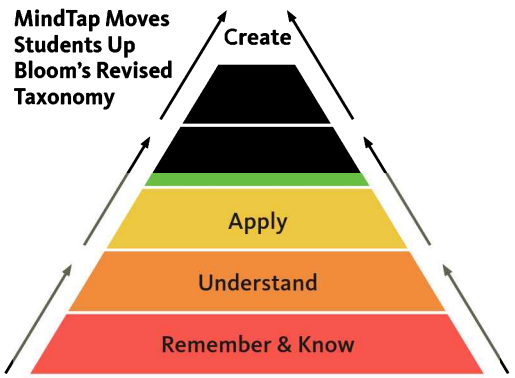
- Engaging them with chapter topics and activating their prior knowledge by watching and answering questions about authentic videos of teachers teaching and children learning in real classrooms.
- Checking their comprehension and understanding through Did You Get It? assessments, with varied question types that are autograded for instant feedback.
- Applying concepts through mini-case scenarios—students analyze typical teaching and learning situations, and then create a reasoned response to the issue(s) presented in the scenario.
- Reflecting about and justifying the choices they made within the teaching scenario problem.

MindTap helps instructors facilitate better outcomes by evaluating how future teachers plan and teach lessons in ways that make content clear and help diverse students learn, assessing the effectiveness of their teaching practice, and adjusting teaching as needed. MindTap enables instructors to facilitate better outcomes by:

- Making grades visible in real time through the Student Progress App so students and instructors always have access to current standings in the class.
- Using the Outcome Library to embed national education standards and align them to student learning activities and also allowing instructors to add their state's standards or any other desired outcome.
- Allowing instructors to generate reports on students' performance with the click of a mouse against any standards or outcomes that are in their MindTap course.
- Giving instructors the ability to assess students on state standards or other local outcomes by editing existing or creating their own MindTap activities and then by aligning those activities to any state or other outcomes that the instructor has added to the MindTap Outcome Library.



Anderson, L. W., & Krathwohl, D. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives.* New York: Longman.

MindTap for Koch, *Science Stories*, 6e, helps instructors easily set their course since it integrates into the existing Learning Management System and saves instructors time by allowing them to fully customize any aspect of the

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learning path. Instructors can change the order of the student learning activities, hide activities they don't want for the course, and—most importantly—create custom assessments and add any standards, outcomes, or content they do want (e.g., YouTube videos, Google docs). Learn more at www.cengage.com/mindtap.

Online Instructor's Manual

An online Instructor's Manual accompanies this book. It contains information to assist the instructor in designing the course, including sample syllabi, discussion questions, teaching and learning activities, field experiences, learning objectives, and additional online resources. For assessment support, the updated test bank includes short-answer and essay questions for each chapter.

PowerPoint Lecture Slides

These vibrant Microsoft PowerPoint lecture slides for each chapter assist you with your lecture by providing concept coverage using images, figures, and tables directly from the textbook.

Cognero

Cengage Learning Testing Powered by Cognero is a flexible online system that allows you to author, edit, and manage test-bank content from multiple Cengage Learning solutions; create multiple test versions in an instant; and deliver tests from your LMS, your classroom, or wherever you want.

Acknowledgments

Developing the sixth edition of *Science Stories* required a close look at the Next Generation Science Standards and its impact on science teaching and learning. The three-pronged approach to science education is reflected by the important stories in this text. Examining the disciplinary core ideas, science and engineering practices, and crosscutting concepts gave new meaning to the stories as they unfolded. Many thanks to Yael Wyner, whose use of electronic resources to develop middle school curriculum in ecology and whose visionary work using Leafsnap informs stories in Chapter 4. Many thanks to Jo Ann Caplin for sharing her remarkable work on *La Bella Principessa*, which informed the story in Chapter 11 and revealed more fully the interdisciplinary nature of science teaching and learning. My former student Christine Bulone Toppi shared her love of science teaching that is reflected by her work on matter with her third graders in Chapter 5. My appreciation goes to Pamela Abder and Robert Wallace at New York University and the IDEAS Institute at Hofstra University.

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The preservice and in-service elementary and middle school teachers with whom I have worked helped me to understand what they needed to be effective science teachers. They also showed me that stories work!

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About the Author

Janice Koch, PhD

Janice Koch, PhD, is Professor Emeritus of Science Education at Hofstra University on Long Island, New York, where she taught courses in science education to future and practicing teachers, pre-K–12. Her research explores encouraging the participation of girls and women in STEM fields and preparing teachers to help foster student learning in science through project- and problem-based experiences. Before joining the university in science teacher education, Dr. Koch taught science in elementary, middle, and high schools in New York City. Her certifications are in earth science, biology, and chemistry, and she consults to science education programs around the country and reviews proposals and evaluates grants for the National Science Foundation. She is also the author of *TEACH*, an introduction to education textbook, and she is past President of the Association for Science Teacher Education.

She wrote *Science Stories* after observing countless elementary and middle school teachers doing science with students. She has traveled all over the world coaching teachers as they engage their students in science experiences. This text is a result of those travels and of thinking about how to show teachers what it "looks like" to teach science effectively. This sixth edition of *Science Stories* makes connections to the Next Generation Science Standards as it encourages teachers to see themselves as scientific and model that for their students.

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PART 1 THE SCIENTIST WITHIN

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CHAPTER 1

Science Teaching and You: Locating Your Scientific Self

Next Generation Science Standards

- **Crosscutting Concepts:** 1, 2, 5, 6
- **Disciplinary Core Ideas:** 4-PS3-2, 4-PS3-3, 4-PS3-4, 5-PS1-1, 5-PS1-2, 5-PS1-3
- **Science and Engineering Practices:** 1, 2, 3, 4, 5, 6, 7, 8

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 1-1 Examine your own science education history.
- 1-2 Examine the nature of science and become familiar with the structure and goals of the NGSS.
- 1-3 Gather data about how people learn and what that means for learning science specifically.
- 1-4 Discuss how to make science meaningful for a diverse student population.
- 1-5 Examine technology's impact on teaching science.
- 1-6 Reflect on and examine your own scientific skills.
- 1-7 Discuss the scientific thinking that pervades your daily life.
- 1-8 Examine how your attitudes toward science affect your performance as a science teacher.
- 1-9 Reflect on society's depiction of scientists through the lens of gender and race.
- 1-10 Examine how writing your science autobiography helps you find the status of your own scientific self.
- 1-11 Start your own science journal to reflect on the natural world around you.
- 1-12 Explain how your personal reflections will help you become a better science teacher.

Reflection

To Think About:

- When you were a child, did you wonder about how things in nature worked? Did you ever try to find out by exploring the world around you?
- If you hear that someone is a "scientist," what does that suggest to you?
- How do you think people learn to understand scientific concepts, and why do so many people have difficulty understanding such concepts?

1-1 An Invitation to Teaching Science

Thinking back to your childhood, you may remember wondering about the world around you—wondering what things were and how they worked. I remember being puzzled, for instance, about how people could fit into airplanes because the planes looked like tiny birds in the sky. I also wondered why we never found a tiny chick when we cracked open chicken eggs. Perhaps you wondered why the sky appears blue, why leaves change colors in some regions in the fall, or why cracks in the pavement appear after an icy winter.

If you and I had such thoughts about the world around us, it stands to reason that other children must have had them as well. In fact, I believe there is a childhood scientist in each of us who is waiting to be awakened. Ever curious about their surroundings, children have an instinct to explore, take apart, and experiment with the things around them. In this way, they propel themselves toward their own important discoveries.

Unfortunately, too often these early instincts are buried by later experiences, including what can feel like the chore of learning science in school. You may have some vivid memories of sitting in a classroom and being bored or stifled by science. If you're lucky, you'll also remember one or more science classrooms that inspired you to think and investigate.

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1-1a The Scientist Within

Where I grew up, in an inner-city neighborhood of New York, summertime recreation was usually afforded by the local park. In addition to playgrounds and sprinklers, there were grassy fields and trees. I often occupied myself by lying in the grass and watching the insects on their journey through the grass and clover. Sometimes an ant would crawl up onto my hand and explore my fingers, my palm, and my wrist. In amazement I would watch this ant as it worked feverishly to find familiar ground, knowing it was not on grassy turf.

The park held many other fascinations. In the early fall, I collected acorns from the huge oak trees, as well as "polly noses," the winged seeds from maple trees found in the northeastern part of the United States (Photo 1.1). Often I would lie on a blanket, looking up in the sky, and make up stories about the clouds. Their formations became animals or dragons, depending on the day.

On occasions when my family and I visited a restaurant, I would always mix the salt, pepper, sugar, and ketchup into the complimentary glass of water on the table. "Ugh," my father would exclaim, "she's making such a mess." "Don't be silly, dear," remarked my mother. "She is exploring. Maybe she will grow up to be a scientist."

As you can see from this story, my mother, although not herself a scientist, had a feeling about what scientists do, and she "coded" my early explorations as "scientific." You, too, are probably more of a scientist than you realize. Chapter 2 will help you explore your scientific self, especially your personal "science baggage"—the experiences that helped shape your beliefs about science and scientists. You'll write about and reflect on those experiences and start your own science journal. These exercises will underscore the relationship between doing science with students and feeling scientific about yourself.

Many people worry that today's elementary and middle school youngsters spend most of their time indoors, on their digital devices communicating with

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PHOTO 1.1 These winged seeds are called samaras. They are from a maple tree and sometimes they are called "polly noses" or "helicopters."

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friends and using different social media apps, or online watching their favorite programs and playing video games. For these young people, the idea of lying on the grass in a nearby park, or even in their own backyard, takes a back seat to the electronic action indoors. We really need to give students a sense of wonder about the natural world, a wonder that can stimulate them to explore and more fully understand the workings of nature.

I firmly believe that it is the task of elementary and middle school science to nurture children's instincts for exploration. If you plan to teach, this book is designed to help you discover and develop the budding scientist in each of your students. It will help you to rethink your ideas about science and science learning. You'll see that all the "why" and "how" questions that students have about their world can wend their way into our classrooms and enrich our teaching of science. And I hope you'll come to understand that science can be a highly personal and engaging experience for students and teacher alike.

This book has a lot to say about personal experiences. I want to take you as directly as possible into classrooms so you can see how science involves teachers and students learning together. Before I do, though, you should know some key ideas that will help you to make the best possible use of this book.

1-2 What Is Science, and Why Teach It?

> *It might seem unfair to reward a person for having so much pleasure over the years, asking the maize plant to solve specific problems and then watching its responses.*
>
> —Barbara McClintock, on Receiving the Nobel Prize for Physiology and Medicine (1983)

Science is a particular way of understanding the natural world, and people have different views of what it is really about. *What do* you *think of when you think of "science"?* Reactions to this question vary. Many new teachers, making word associations, think "test tubes," "laboratories," or "white coats." Some people think of science as a subject that holds the key to understanding the secrets of the universe. That sounds exciting—and a bit mysterious as well. Too many people, unfortunately, think about a long list of facts to be memorized—a common notion of school science.

Whatever our associations, we should remember that science is basically an area of knowledge created by people—men and women—who devote much of their energies to exploring some part of nature and trying to make sense of it. In this sense, human societies have a long tradition of scientific exploration. Ever since the dawn of civilization, people have studied nature and tried to understand it.

1-2a Science as a Set of Practices, a Set of Ideas, and a Way of Thinking about the World

Understanding the nature of science includes knowing both *what* science knows and *how* science knows what it knows. In schools, we often teach only what a specific field of science knows, not the genuine nature of science itself. According to one scientist writing about the enterprise, "The central ideas involve observation of the world and the constant testing of theories against nature, with

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the requirement that everything that is to be called science is testable" (Trefil, 2008, p. 19). To me, the best definition of science takes account of three different facets of the subject. Science can be described as a *set of practices*, a *set of ideas*, and *a way of thinking*.

The middle part of that definition, the "set of ideas," is probably familiar to you. The mention of science typically conjures up images of biology, chemistry, physics, geology, and earth science—the subjects commonly taught as science in schools.

The notion of science as a set of practices and as a way of thinking may be harder to grasp. Yet these parts of the definition have important implications for the "set of ideas" part of the definition of science. As they explore nature, scientists use specific practices that help them to learn more about their area of study. This process is sometimes referred to as THE **scientific method**. In fact, there are many scientific methods, but they all have some principles in common. A very important point to recognize about the practices of science is that, while scientists work in similar ways to test their ideas, *there is no one single sequence of steps followed in all scientific investigations*. Hence, when textbooks devote a whole chapter to "The Scientific Method," they give the false impression that there is just one way to do science. In fact, scientists use many different approaches to making observations and testing their ideas. Throughout this book we will have a great deal to say about the practices of scientific activity, but do remember that scientists are not robots and that the best scientific thinking is creative as well as rigorous.

scientific method
The typical process that scientists use in the course of studying natural phenomena, including steps such as observation, forming a hypothesis, and experimentation to test the hypothesis.

Doing Science: A Set of Practices Science as a set of practices is based on the premise that we can use our senses and extensions of our senses—that is, instruments or tools—to give us accurate information about the natural world. Scientists begin by exploring the questions about nature that engage them. The questions themselves are not necessarily obscure. Your early wonderings that I spoke about at the beginning of this chapter could in fact lead to a scientific question. This is true of many children's wonderings. A friend once asked Isidor Rabi, a Nobel Prize winner in physics (1944), how he became a scientist. Rabi replied that every day after school his mother would talk to him about his day. She wasn't particularly interested in what he had learned that day, but she always inquired, "Did you ask a good question today?" "Asking good questions," Rabi said, "made me become a scientist" (Friedman, 2007, p. 301). As you will see throughout this book, discovering students' questions—what they wonder about—is both fascinating and exciting.

It is often said that being a scientist is less about what you know than about how your brain is wired to ask questions! Then what makes a question a scientific question? A question is considered scientific when, in order to find the answer, people usually engage in actions that include:

- Making careful observations.
- Coming up with an explanation to make sense of these observations.
- Setting up an experiment to test the idea.
- Exploring the results and trying to make sense of them.
- Asking others to repeat the experiments.

These steps reflect some of the basic processes of science. Scientists collect information through careful observation of nature and natural phenomena. They explore and test their ideas by setting up experiments (and, sometimes, by trial and error). Others repeat their experiments in the search for consistent outcomes. To help make one set of results comparable to another set, different scientists follow similar procedures in their investigations.

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FIGURE 1.1 Science and engineering practices

Science and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analyzing and interpreting data.
5. Using mathematics and computational thinking.
6. Constructing explanations (for science) and designing solutions (for engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating and communicating information.

Source: NGSS Lead States (2013), App. F.

This overall process of asking questions about how the natural world works, carrying out investigations, and developing explanations based on our evidence describes science practices and is often referred to as the process of **inquiry**. Engaging students in inquiry has been a major theme of elementary and middle school science education since the National Research Council published the first *National Science Education Standards* in 1996. Inquiry may also be thought of as "science as practice." Hence, science is something we do, and science practices include the experiences and the conversations that help us to understand the concept.

inquiry
The type of exploration that lies at the heart of scientific activity. According to the *National Science Education Standards*, inquiry is "a multifaceted activity that involves making observations; posing questions; . . . planning investigations; . . . using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results" (National Research Council, 1996, p. 23).

In 2013, the National Research Council developed a framework for the Next Generation Science Standards (NGSS) to provide a vision of what it looks like to be proficient in science. It describes science as a body of knowledge as well as an evidence-based enterprise that continually refines and rethinks that body of knowledge. The three dimensions of the NGSS include the **science and engineering practices**, the **disciplinary core ideas**—those science concepts that have broad importance across several branches of science, and **crosscutting concepts** that are a way of linking and thinking about the different areas of science.

science and engineering practices
The use of a particular set of practices for engaging in scientific inquiry and engineering.

disciplinary core ideas
Science concepts identified by NGSS that have broad importance across several branches of science.

crosscutting concepts
A way of linking and thinking about the different areas of science.

Engaging in scientific practices helps us to understand how scientific knowledge develops and engineering practices give us insight into how engineers work. The science and engineering practices described by the new standards are given in Figure 1.1.

Engaging in these practices requires many skills, such as observing, predicting and making inferences, classifying, and planning an experiment, to name a few. It's important to realize that the science practices and skills come into play not just in science labs but in all areas of life in our increasingly complex world. Often we use these practices without even "coding" them as scientific. Every day, for example, you make observations about the weather and decide what to wear on the basis of your observations. In doing this, you are observing and predicting. You may be gathering data as well, such as the temperature and humidity outside. In later chapters we will explore these practices in detail.

A Set of Ideas By using the science and engineering practices and through much repetition, scientists develop concepts about the natural world. These concepts are often referred to in this book as "science ideas." To put it simply, they are understandings about the natural world. Most high school science textbooks are filled with these understandings. The NGSS refers to them as "disciplinary core ideas" (DCIs) that are essential for students to know before they graduate from high school. These core concepts are central to our understanding

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A disciplinary core idea for K–12 science instruction is a scientific idea or practice that:

- Has broad importance across multiple science and/or engineering disciplines and/or is a key organizing concept of a single discipline.
- Provides a key tool for understanding or investigating more complex ideas and solving problems.
- Relates to the interests and life experiences of students or can be connected to societal or personal concerns that require scientific or technical knowledge.
- Is teachable and learnable over multiple grades at increasing levels of sophistication and depth.

of how the natural world works. These are science ideas in life, physical, and earth and space sciences as well as engineering, technology, and applications of science. There are also core concepts that help us to understand how science works. These concepts describe the nature of scientific activity or what is called the "nature of science" (NOS).

To be considered a DCI, a science concept must have broad importance across the branches of science and engineering or be a key foundational concept for more difficult ideas. As we examine the stories of teachers and students doing science together, we will relate the science content in each story to a DCI. We will also examine how these DCIs get understood at progressively different levels as students go on to the next grade.

Science ideas include definitions and explanations of natural phenomena. For example, in physical science, energy is often defined as the ability to do work. Science books define work as the process by which a force moves a given mass through a distance. The NGSS states that "Energy is present whenever there are moving objects, sound, light or heat." This is a disciplinary core idea in physical science for grades 3–5. This DCI continues to explain that "When objects collide, energy can be transferred from one object to another, thereby changing their motion." Scientists calculate the amounts of energy that are required to do different kinds of work in nature. As this example shows, the language of science sometimes uses terms differently from the way they are used in everyday life.

An important example of that difference is the term *theory*. A report from the National Academy of Sciences explains that, in daily language, a theory often refers to a hunch or a speculation. In formal scientific use, however, a theory is "a comprehensive explanation of some aspect of nature" that is supported by a considerable body of evidence. As an example, the concept of evolution—the idea that living things attained their present forms by a process of changing over time—may still be labeled a theory rather than a fact, but that theory's basic components are so well-tested that most scientists believe they will never be overturned by new evidence, no more than the once-controversial theory that the Earth revolves around the Sun (National Academy of Sciences and Institute of Medicine, 2008, p. 11).

theory
A comprehensive explanation of some aspect of nature that is supported by a considerable body of evidence—in other words, the best explanation we currently have for why something is so.

Theories and other scientific ideas are inseparable from science practices. Without the process, there could be no ideas. Without ideas to spur more questions, there would be no need for further processes.

A Way of Thinking about the World Science as a way of thinking about the world includes a desire to find evidence to support statements as well as an open-mindedness and willingness to change one's mind when confronted with

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new evidence. This is really what is meant by thinking scientifically. Because scientists often work collaboratively, the scientific way of thinking about the world also includes a willingness to cooperate with others and advance everyone's understanding through group effort.

Earlier in the chapter, we mentioned the three dimensions of the NGSS. While we touched upon science and engineering practices and mentioned the disciplinary core ideas, the third domain, the crosscutting concepts, affect our notions of science as a way of thinking about the world. These crosscutting concepts include: (1) patterns, (2) cause and effect, (3) scale, proportion and quantity, (4) systems and system models, (5) energy and matter: flows, cycles and conservation, (6) structure and function, and (7) stability and change.

Consider this activity as an allegory for how science works and a way to think about the Nature of Science.

A class of twenty college students is divided into five groups. Each group of four students receives an identical set of sixteen canceled checks from the same family. The checks are in sealed envelopes, and each group is allowed to randomly select four checks at a time. After each round of check selection, group members are asked to record the ideas they have developed about the family as a result of exploring their canceled checks. After all sixteen checks have been analyzed in relation to the others, the group recorder writes down—on a large piece of poster paper for all to see—the tentative conclusions that the group has reached about the family. For example, there are canceled checks to wedding planners, to healthcare providers, and to judges! The checks have dates, signatures, addresses, and sequential numbers. All the students have examined their groups of four checks in random order. *Do you think the order in which they see the checks makes a difference?*

When the students review all the conclusions, they find that each group's story varies in many ways from the others—except for three or four main ideas about the family. The class members decide that these three or four ideas are ones that they can begin to call their *theories* about this family. They suggest ways to explore their family theories further. How do they know they are right? They ask me, their professor, if I know the right answer. I do not. They are annoyed, but I am an explorer, too!

How does this story relate to the nature of science? The canceled-check activity is an excellent metaphor for the way scientists work:

- Just like the student groups, several scientists often explore the same problem with identical evidence but in different sequences.
- The order in which the students select their checks from the envelopes influences their story. Similarly, scientists often find that the sequence in which they have encountered their evidence influences their developing ideas.
- The discussion each student group has about the evidence also influences the outcomes. Scientists, too, work in groups and confer about their evidence regularly.
- The crosscutting concepts of the NGSS relate to how the groups examined their checks. Were they looking for ***patterns*** *or seeking* ***cause and effect relationships***?
- Finally, unlike many school science experiences you may have had, real science proceeds to find answers where no previous answers exist. Similarly, the students in our example develop theories based on how they see the evidence and what their own experiences tell them. They do not pursue preexisting "right" or "wrong" answers.

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Such is the nature of science: a quest for new knowledge based on repeated efforts to explore the evidence and draw conclusions within a social community of workers.

1-2b The Value of Teaching Science

Lurking in the back of your mind may be a question about why we teach science before high school. The answer has three parts, corresponding to our three-part definition of science.

1. The set of ideas that we are calling science ideas or "disciplinary core ideas" helps us understand how the natural world works. Many educators, cultural commentators, and leaders of industry have stated that knowing what science is about is crucial for everyone. Many of today's jobs require some scientific knowledge, and even our everyday decisions—from what to eat to which vehicle to buy—can be affected by our scientific understanding or lack of it. In today's world, it's never too early to begin learning science, and elementary and middle schools are expected to do their part.

   To many educators, the ideas from environmental science are especially important. A good science program will help youngsters understand the ways in which we are depleting the natural resources of the earth. The branch of environmental studies popularly called **green science** includes the study of sustainability, food webs, resource distribution, and the changes in our climate. Understanding how natural systems work and appreciating irreplaceable natural wonders will enable future students to become stewards of our planet.

green science
The branch of environmental studies that includes the study of alternative and renewable energy, food webs, conservation, resource distribution, and the changes in world climate.

2. The skills that students acquire by engaging in the practices of science are useful in many fields other than science. In fact, the Common Core State Standards for Mathematics and English Language Arts (2010) emphasize the role of citing evidence, for example, as students make claims about what they read, or, in the case of mathematics, asking students to make sense of the processes behind their mathematical computations. Elementary and middle school students who engage in scientific activities in their classroom build confidence in themselves as thinkers.

3. By cultivating a scientific way of thinking about the world, we can help students improve their abilities to explore a problem from many perspectives, confer with their classmates and their teacher, and become knowledge builders and meaning makers. Understanding how science works helps people grasp the nature of evidence and the conclusions we can reasonably make about the world around us.

In all these ways, science learning prepares students not just for biology and chemistry but for English, history, and social studies as well—and, in the most fundamental sense, for life. As one study reminds us, "science is a significant part of human culture and represents one of the pinnacles of human thinking capacity" (Duschl et al., 2007, p. 34).

1-2c Teaching Science and the STEM Education Movement

You may be wondering why the NGSS elucidate the science and engineering practices. Engineers design solutions to problems and often create new products and processes. Fostering creativity in science is related to problem solving

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in engineering. The STEM education movement (2010) represents the intersections and connections among science, technology, engineering, and mathematics and was inspired by a need to encourage students to engage in new approaches to finding solutions using the tools of several disciplines. This is the goal of the NGSS, representing the DCIs and the science and engineering practices, and crosscutting concepts that cross over the boundaries of scientific disciplines and give us a way to see the concepts as multi-disciplinary. As you read the stories in this text, think about what crosscutting concepts are represented when students engage in doing life, physical, and earth and space science. Imagine the importance of thinking about systems and system models in order to understand human body systems or the solar system! Problem solving through engineering design, the "E" in the STEM education movement, helps students to appreciate the role of engineers in solving problems by creating new processes and products.

1-1a The Teacher Makes a Difference

One thing is certain. The success of the science lesson depends upon the teachers who implement it. You need to ask yourself if you feel good about doing science with your students and if you are willing to put in the planning and preparation that will help the students engage in the practices of science. After reading this text, I am hoping you cannot wait to get started! Part of that journey is reflecting on how students learn and locating your own scientific self.

1-3 How Do Students Learn Science?

Learning about learning is one of the tasks associated with becoming a teacher. In particular, understanding how students *learn* science is vital to becoming an effective science teacher. This intricate and complex subject is one of the most exciting challenges in teaching. As you prepare for your chosen profession, you have the opportunity to learn about the ways students learn not just from books and lectures but directly from and with their classmates.

First, though, it will help you to have some grounding in the ideas of other professionals who have studied the subject. Many individuals have made important contributions to our understanding of how students learn. The scholars, philosophers, and learning theorists who have most influenced this book are John Dewey, Jean Piaget, Jerome Bruner, Lev Vygotsky, and, more recently, John Bransford and Suzanne Donovan. Although these thinkers did not always agree completely, I have developed my own model of teaching science based on much of their thinking. This model is particularly influenced by a family of theories about knowledge and learning called constructivism.

constructivism
A family of theories about knowledge and learning whose basic tenet is that all knowledge is constructed by synthesizing new ideas with what we have previously come to know. This means that knowledge is not passively received. Rather, knowledge is actively built up by the learner as he or she experiences the world.

1-2b Key Tenets of Constructivist Theory

Basic to **constructivism** is the idea that all knowledge is *constructed*. This means that knowledge is not passively received. Rather, it is actively constructed by the learner as he or she comes to experience the world.

This sounds like a simple notion, but, in fact, it is not. It describes a complex and recursive process by which learners engage in experiences, think about those experiences, see how they fit in with their prior constructions, and then, sometimes, formulate new constructions. Figure 1.2 illustrates this pattern in the way our minds work.

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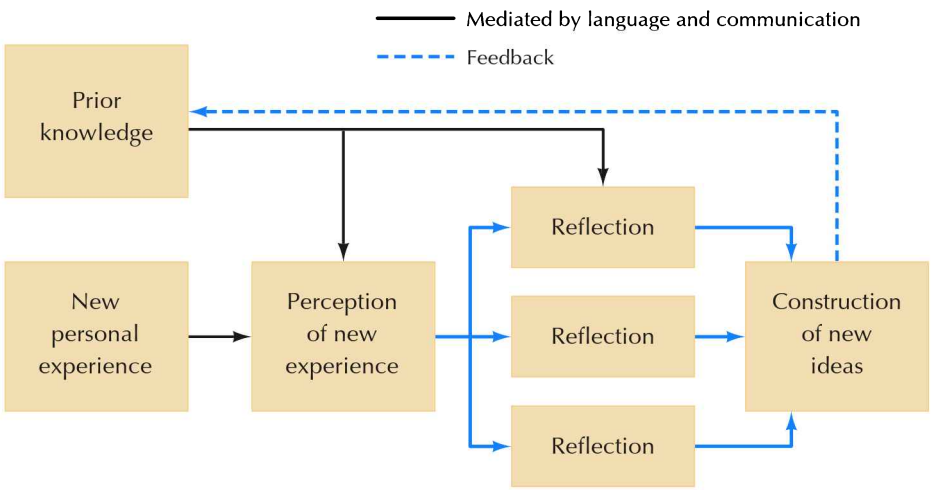

FIGURE 1.2 Constructing meaning from experience: a generalized diagram of a typical process

Piaget and Bruner One of the key contributors to this understanding of the learning process was the Swiss scholar and scientist Jean Piaget. Beginning in the 1920s, Piaget conducted countless interviews and research studies with children of varying ages. He was able to describe *stages of cognitive development* that the children passed through—that is, specific times in the children's development when different mental structures began to emerge. Although he recognized that children vary, he pegged his stages of development to general age ranges. For example, he believed that most children are in the sensorimotor stage when they are between eighteen months and two years of age and in the preoperational stage when they are between two and seven. He also believed that a child's progress through the stages is biologically determined. Most important for our purposes, Piaget concluded that the growth of knowledge is the result of individual constructions made by the learner. In other words, Piaget decided that knowledge is not passively received but is actively built up by the learner—a process of invention or creation, not reception. As he recognized, this gives tremendous responsibility to the learner.

In describing the stages of cognitive development, Piaget demonstrated that, at each stage of maturation, the child is ready for a different type of learning. That is, the types of ideas that learners construct vary with each maturational stage. Some critics of Piaget's stages assert that children can be in several stages at the same time and that the stages cannot be neatly defined by specific ages.

discovery learning
A phrase popularized by learning theorist Jerome Bruner, who suggested that, at any given stage of cognitive development, teaching should proceed in a way that allows children to discover ideas for themselves.

Jerome Bruner, a leading supporter of Piaget's work, suggested that, at any given stage of cognitive development, teaching should proceed in a way that allows children to discover ideas for themselves. His work became known as **discovery learning**. He differed from Piaget in one important respect. Whereas Piaget believed that readiness for a particular type of learning depended on a child's stage of cognitive development, Bruner noticed that children are always ready to learn a concept *at some level*. Realizing this, Bruner emphasized the importance of returning to science topics at various ages, of revisiting them at different stages of the child's development (Bruner, 1960). This produces a *spiraling* of science curriculum topics, as the same broad topics are revisited at higher grade levels. For science topics that educators and scientists see as meaningful and relevant for students' lives, this practice has become an important part of curriculum planning.

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For many years, Piaget's stages of development and Bruner's discovery learning ideas were the basis for teaching science. Common to these theorists' views is the understanding that:

- Children are active knowers.
- Children construct their ideas on the basis of their experiences of the world.
- Children's prior knowledge—that is, what they have learned from all their previous experiences—plays a crucial role in determining how they integrate a new concept.

This last concept, concerning children's prior knowledge, warrants further reflection. It demands that we recognize that all students come to the classroom with funds of knowledge based on their past experiences. In fact, students arrive at our doors with varying ranges of experiences and therefore varying types of prior knowledge. It is fascinating to discover how students think about new experiences on the basis of where they have been and how they have lived before we met them.

This way of understanding learning requires us to view our students as "knowers"—even before we teach them anything. Indeed, they *are* knowers. Young as they may be, they have lived several years and acquired many experiences before meeting us. Their experiences have led them to construct their own ideas about the world. These ideas become the framework on which they try to "fit in" new ideas. It is as though the students ask themselves, "How does this match my prior thinking? Where can I place it?"

Indeed, perhaps the most important thing to know about your students is what they already know! We need to understand students' existing beliefs in order to help them construct new ideas. As you will see later in this book, having conversations with your students about their prior understandings helps both you and them gain insight into their thinking.

Vygotsky and the Social Context Piaget's work, which dealt in detail with the individual learner, was criticized for not taking into account the learner's social context. Constructing an understanding of the world does not happen in a social or cultural vacuum. The Russian psychologist Lev Vygotsky demonstrated how social contexts influence the ideas that individuals construct as they communicate with each other. For instance, the teacher and students in a classroom use language that is socially and culturally accepted in their specific environment. This language may include slang, regional dialects, or other special usages. The ideas that students construct in the classroom conform to these socially accepted usages and meanings. Brooks and Brooks (2001) put it this way: "Coming to know one's world is a function of caring about one's world. Caring about one's world is fostered by communities of learners involved in trying to answer similar ... problems" (p. 30).

Learning Theory, Big Ideas, and Metacognition In a wonderful children's story by Leo Lionni (2005), *Fish Is Fish*, a little minnow meets a tadpole in a pond at the edge of the woods. At first, they think they are both fish, but before long the tadpole grows tiny front legs, becomes a frog, and climbs out of the water to live on land. The minnow grows too, into a fish, and misses his friend. When the frog returns for a visit some time later, he describes to the fish all the wonderful things he saw on land: birds, cows, men, women, and children! But, as the fish hears the story, he pictures these creatures as fish with wings and feathers, or as fish with legs and hats and coats, and the wonderful illustrations provide the reader with the fish's personal context.

As the story proceeds, the fish pushes himself out of the water to see what his friend the frog described. As he is gasping for air, the frog appears and

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nudges the fish back into the pond. The relieved fish begins to understand that a fish cannot be a frog and that indeed "fish is fish."

Learning researchers use this story to illustrate the ways in which new understandings are constructed on a foundation of existing understandings and experiences (Donovan & Bransford, 2005). Just like the fish, students use what they know to shape their new understandings. Sometimes what children know is rooted in a misconception, and this becomes a barrier to new learning. Childhood misconceptions can become barriers to adult science learning unless they are addressed directly.

But what about the frog? He was not a very good teacher since he left out the important idea that the birds, people, and cows looked nothing at all like fish or frogs! In addition to the role of prior knowledge, learning researchers have discovered that factual knowledge must be placed in a conceptual framework to be well understood. We refer to this as the **science idea or big idea** or the overarching core concept that, when unpacked, leads to discrete facts. In the *Fish Is Fish* book, the big idea is that different species (fish, amphibians, birds, and mammals) have different identifying characteristics that allow them to live in different environments.

science idea or big idea
An overarching concept that is the organizing principle behind a number of discrete scientific facts.

Learning researchers also believe that the learner must reflect on her or his ideas and make personal sense of these ideas. This capacity to "know what you know"—and what you do not understand—is called **metacognition** or self-monitoring (Donovan & Bransford, 2005).

metacognition
Self-monitoring, with the capacity to "know what you know" and what you do not yet understand.

1-2b Implications for Teaching

As we have seen, prior knowledge and metacognition both relate to constructivism and our understanding of how people learn. But you may wonder why understanding learning theories is so important in contemporary science education. It is because researchers have found that traditional methods of instruction are inadequate to help students form deep meanings and thoughtful understandings of ideas. We have come to understand that the stimuli we receive are simply not enough to convey meaning—that, for example, merely reading this book is not sufficient for gaining understanding. To really grasp the meaning of concepts, the learner has to make sense of that concept on his or her own terms and construct and reconstruct the meaning.

It makes sense, therefore, to think about organizing our teaching practice to reflect this understanding. By that, I mean that we can translate this theory of knowing and learning into a theory of teaching practice. That is one of the goals of this book: to help you translate the theory into practice in your own classroom.

Concrete Experiences One common classroom technique is to have students interacting with objects and materials in the students' real world. These concrete experiences are also called "hands-on experiences" because they typically engage students in exploring materials by physically manipulating them. For example, students studying electricity may work with batteries, bulbs, and wires to construct different types of electrical circuits, or for a science unit on fossils and ancient lifeforms, students may take a trip to a museum to explore the remains of dinosaurs.

From engaging in such activities, students develop ideas about the natural world and begin to construct their own ideas and meanings in the way described by Piaget and Bruner. So, when we think of "learning science," we can envision it as a process of making meaning from concrete experiences. Also, as Vygotsky pointed out, it stands to reason that this process of meaning making is influenced by children's social interactions. Therefore, when we think about students learning science, we should imagine them engaging in concrete experiences *along with* their peers and their teachers. Science as practice refers to doing

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"Delivering" Science Instruction

Imagine that you receive the following reading assignment in a science class:

The Montillation of Traxoline

Traxoline is a new form of zionter. It is montilled in Ceristanna. Ceristannians gristerlate large amounts of fevon and then bracter it to montil traxoline. It is very important to learn about traxoline. It is one of our most lukized snezlaus.

Now imagine that you have to respond to the following questions with the correct answer:

1. What is traxoline?
2. Where is it montilled?
3. How is it made?
4. Why is traxoline important?

On the basis of the reading, you can probably answer all of these questions correctly. For example, for question 4, you would write, "Traxoline is important because it is one of our most lukized snezlaus." You would score 100 percent on the assignment. But what does it mean that all your answers are correct? How much will you remember tomorrow?

The above paragraph was developed by Judith Lanier at the Michigan State University as a useful metaphor for the way science is often taught and assessed. Of course, there are no such substances as traxoline and fevon, and Ceristanna is not a real place. But by reading the paragraph and answering the questions, you can see how little you gain by memorizing new terms and facts that have no meaning in your own mind. It is important to learn about traxoline because it is sure to be one of our most lukized snezlous in the future.

something and learning something in such a way that the doing and the learning cannot be separated (Michaels, Shouse, & Schweingruber, 2008). As you read the science stories in this text, you will see the teaching ideas behind the story and the science ideas behind the story—both the doing and the learning get deconstructed for you—but the experience is one whole. What is important is to engage students in doing science and the detailed discussion and reflection that accompanies it.

Hands-on activities have been common in science lessons for decades. However, three crucial elements are often left out:

1. *Connections to the students' own lives.* Because, as learners, all of us try to fit new experiences into what we already know, it follows that we will learn most readily if we can find the proper fit. If students view a school science experience as being completely unrelated to their lives, they are not likely to learn from it. To help students see the connections, we need to begin by valuing their own prior experiences and their own thinking. After all, it is through their own thinking that they construct new ideas.
2. *Opportunities for the students to actively reflect on their experiences.* This is extremely important. The process of active engagement must include discussion and reflection in order for the meaning making to happen. When hands-on science became a prominent science teaching movement, many well-meaning teachers used the experiences but neglected to reflect on them with their students—and not much science learning took place. After all, the real learning is not situated in students' hands but in their minds. Some people therefore prefer to speak of "hands-on/minds-on" science.
3. *Clearly defined conceptual goals for the students.* As the teacher, you must have an idea of where your students' active experiences will lead them. There may be many ways for students to make meaning about a science concept, but you yourself need to be clear about where you are taking them. Then

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you can help the students use their initial ideas to progress toward new ideas. In this way, you can extend their thinking and help them to create new understandings of the natural world. You will see many examples of this process in later chapters.

Meaningful Experiences With the basic notions of constructivism in mind, we can say that its most important implication for teaching practice is that the learner must be actively engaged in science activities in order to construct new ideas about the natural world. We often refer to such activities as **meaningful science experiences**. A science experience can be considered meaningful if it:

meaningful science experience
An activity that engages students in the key processes of science, such as observing and predicting, inferring and hypothesizing, manipulating objects, investigating, and imagining; that relates to the students' everyday lived experiences; and that stimulates the students to reflect on what they are exploring and come up with their own ideas.

- Relates to the students' everyday lived experiences and to a larger, overarching concept or big idea.
- Engages students in science and engineering practices using skills like observing and predicting (Photo 1.2), inferring and manipulating objects, investigating, developing and using models, arguing from evidence, and constructing explanations.
- Stimulates the students to reflect on what they are exploring and to come up with their own ideas.
- Reveals the students' own thinking, leading to metacognition.
- Leads to new understanding and the ability to communicate new science ideas to others.

This book can help you to construct meaningful experiences in science for your students. It will also help you understand the role a teacher plays in this process. Teaching science has a lot to do with providing students with experiences and listening to their ideas, as the following science story shows.

Michael Newman / PhotoEdit

PHOTO 1.2 What does it weigh? These kindergarten children weigh objects and record their mass—a concrete experience that uses the scientific processes of observing and manipulating materials. If the children also reflect on what they are doing and construct their own ideas, the experience will be truly meaningful.

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SCIENCE STORY

Listening to Students' Ideas

Darlene McKie's third-grade class is studying sound energy. Ms. McKie has carefully engaged the students in experiences that should lead them to understand that sound travels by means of vibrations through a substance. The substance can be a gas, such as air, or it can be a solid or a liquid. The children use instruments to tap the base of their desks while holding their ears to the desktop. They "hear" the sound made through the desk. They also tap rocks together underwater in pails and hear the sound made by the rocks. They place vibrating tuning forks in shallow pans of water and watch as the water splashes. Terms like *sound* and *vibrations* are used often in this classroom.

After these hands-on activities, Ms. McKie gathers the students around to discuss their ideas. She asks the class, "Why isn't there sound on the moon?" The children sit quietly, unsure what the teacher is "looking for." Ms. McKie then explains, "There is no air on the moon, so there is nothing to vibrate, and there is no sound on the moon."

One girl, Terri, raises her hand and says, "But the moon is a solid, right?"

"Yes," replies Ms. McKie.

"So if sound travels through a solid like a desk," Terri continues, "why can't sound travel *through* the moon?"

Ms. McKie realizes that Terri is grappling with the abstract concepts of sound energy and what it means for sound to "travel." Wisely, Ms. McKie looks at the class and then opens Terri's question up for the group's consideration, even though the day is carefully scheduled and Ms. McKie is going over the allotted time for science.

Listening and Mediating What do you think of Ms. McKie's decision to discuss Terri's question with the class?

In classrooms, scientific knowledge is often bundled into packets of information associated with a manipulative activity or experience. Under constraints to meet local state requirements for time spent on standardized testing, teachers often experience pressure to "cover" curriculum and are forced to ignore the processes required for thoughtful consideration of a topic. Yet everything we know about how learners construct meaning flies in the face of rushing through activities and their related concepts. If Ms. McKie had cut off the discussion of Terri's question, she would have cut short the possibilities for building useful concepts. The role of the teacher in this scenario is one of an active *listener* and *learner*. As much as we know about a topic, we cannot know *everything*. We can, however, come to know our students' thinking and follow their ideas to a reasonable conclusion—even if the conclusion is that "sound may travel through the moon, but we are not sure." With this process, we validate the fact that the students have been grappling with a significant concept and that in their struggle to understand they have come up with a new idea.

Ms. McKie could follow up on this idea about sound traveling *through* the moon by encouraging the students to learn more about the composition of the moon. Over 840 pounds of moon rocks were brought back from the Apollo Missions of the 1970s, and they have been analyzed and explored in detail. Astronomers even know that there is a very thin atmosphere on the moon, though not enough to allow sound vibrations to travel! As you can see, there are many paths that the students' imaginations can take, and an effective teacher will help them explore their own ideas.

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Instead of *telling* students what to think, therefore, you will listen closely to them and become a *mediator* of their thinking. You will help them to learn by reflecting their own ideas back to them and guiding them in sorting out the inconsistencies. Chapter 2 will develop this idea further, and you will see many examples of the teacher as mediator throughout this book.

Teaching Science for Understanding As we explore some of the models for science teaching, it is important to keep in mind that the twenty-first century demands novel ways of solving problems, critical thinking about issues and ideas, and an ability to take ideas apart and put them together again. Our methods for teaching science must respond to the complexities of our society by stressing what some science educators refer to as "meaning over memorizing, quality over quantity and understanding over awareness" (Mintzes, Wandersee, & Novak, 1998, p. xvii). But what does it mean to understand something, and how do students demonstrate understanding? As Perkins puts it, "Understanding goes beyond knowing. ... Understanding a topic is a matter of being able to perform in a variety of thought-demanding ways with the topic, for instance to: explain, muster evidence, find examples, generalize, apply concepts, analogize, represent in a new way, and so on" (1993, pp. 28–29).

In other words, as we mentioned earlier, learning with understanding requires that factual knowledge be placed in a conceptual framework in order for it to be understood. I like to think of the "big idea" or conceptual framework as a closet and the facts as hangers in that closet. Both are necessary for learning with understanding (Donovan & Bransford, 2005). Think back to the *Fish Is Fish* story. The facts include the details about the appearance of people, birds, and fish. People have legs; birds have wings. The big idea is that these differences among species mean that people and birds can live on land but not in water, and fish can live in water but not on land.

One fundamental question this textbook emphasizes involves your understanding of what you want for yourself and for your students. What is enough for you? What are you satisfied knowing? What is it that you want your students to understand?

The Learning Cycle To teach science for understanding, many educators use the **learning cycle** approach, which incorporates much of what we have been saying about concrete and meaningful experiences and the importance of listening to students' ideas. This method has its roots in experimental science programs designed over fifty years ago, most notably the Science Curriculum Improvement Study (SCIS). The learning cycle approach is based on a series of five phases, although it is sometimes collapsed into a smaller number. However many steps it employs, the learning cycle is a useful tool for teaching science and for designing your lessons. In its five-phase version (sometimes called the 5E learning cycle), the learning cycle takes this form:

learning cycle
An approach to teaching science that typically includes five phases of science teaching and learning: engagement, exploration, explanation, elaboration, and evaluation.

1. *Engagement Phase.* The first phase of the science learning cycle engages students in the topic at hand by inviting them to think about it, explore an opening demonstration, or come up with everything they may already know about the topic. This is the "hook": How can you get your students interested in and on board with the topic?

   This is also the time when students begin to call up their prior knowledge and assumptions about the subject. In Chapter 7 you will see a middle school class in which students place an apple and a similar-size potato in a clear container of water and try to make sense of what they observe. The apple floats and the potato sinks. This question draws out the students' own experiences with floating apples as well as their personal theories about why apples float but potatoes sink.

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2. *Exploration Phase.* This phase invites *students* to explore a problem by manipulating materials. Students interact both with each other and with the materials as they work to find optimal solutions to the problem. The teacher facilitates the students' work and visits with them as they handle the materials and perform tests. With the teacher's encouragement, students look for evidence that supports or challenges their original understandings and assumptions. To investigate the apple–potato problem, as you'll see later, the students engage in direct experimentation with apples, potatoes, and basins of water to test their ideas about floating and sinking.

3. *Explanation Phase.* The third phase involves the teacher interacting with the students as they begin to develop explanations for what they have observed. In the apple–potato experiment, the student science groups share their ideas about apples and potatoes and about why objects sink or float. Their reasoning becomes more visible, and the teacher begins to see some metacognition. This is the time when the teacher deeply explores the students' thinking. In this book, I am talking largely about this phase when I refer to the teacher's role as a "mediator" of students' thinking.

4. *Elaboration Phase.* In the fourth phase of the science learning cycle, teachers take advantage of opportunities to make connections between the science concept, the students' lives, and the students' prior knowledge. During this phase, students may come up with their own ideas and may want to test them or discuss them—like the girl in Ms. McKie's class who asked about sound traveling through the moon. In the apple–potato investigation, students peel the apples and potatoes, take out the apple core, change the shape of the potato, and pursue other interesting elaborations of the original experiment. The big idea—namely, the density of materials and its effect on sinking and floating—begins to emerge.

5. *Evaluation Phase.* During this final phase, teachers explore what the students know and are able to do as a *result* of their experience. For this purpose, teachers can use various assessment techniques, as described in Chapter 12. Students are often encouraged to assess their own understanding of a topic and apply it to another context. For instance, the students who have explored the density of sinking and floating fruits may be asked to think about other natural phenomena where density plays a role.

Many of the ideas described by these five phases will be recognizable to you as you read the coming chapters. For simplicity in planning lessons, you can collapse the five-phase model into three phases:

1. Engagement and Exploration
2. Explanation and Elaboration
3. Evaluation and Application

As long as the students are engaged with materials, trying to make sense of their observations, and testing their explanations against their observations, there is a good chance they will be doing and learning science!

Students' "Misconceptions" As you can imagine, the prior knowledge that students bring to a lesson is not always correct in scientific terms. Sometimes children (and adults, too) use their experiences to develop ideas that are misconceptions—inaccurate ways of understanding the natural world.

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For example, if you merely observed sunrise and sunset every day, you might think that the sun revolved around the Earth, instead of the Earth's moving around the sun. Some researchers in science education have called such ideas "prescientific conceptions," while other researchers refer to them as "alternative conceptions."

In fact, there is a strong movement away from referring to these ideas as "misconceptions" because that term implies that they are simply wrong, have no value, and should quickly be discarded. Therefore, *alternative conceptions* is the preferred term. Constructivist philosophy suggests that all of the learner's ideas—even the ones we think obviously wrong—have some value because they are part of a process that eventually can lead to a better understanding of the natural world. One science teacher remarked that alternative conceptions are like stepping-stones that students construct. With the teacher's help, these stepping-stones eventually lead to a full understanding of the scientifically accurate concept.

Again, it is important to value the ideas that learners offer. This is the first step in helping students construct new ways of seeing. Throughout this book, you will find illustrations of how this approach can work in the science classroom.

This Book's Approach Drawing on the many teaching implications of learning theories we can summarize this book's approach to science teaching as follows:

- Think about the core science concept or DCI that you are hoping the students will learn.
- Engage students in meaningful scientific activities.
- Encourage them to think about the activities and reflect on what they found out.
- Pay attention to the prior knowledge and alternative conceptions that the students bring to each learning experience.
- Listen to the students' thinking and regularly engage them in conversation about their ideas.

1-4 The Diversity of Science Students

As you will discover in the following chapters, making meaning from collaborative science activities is both social and personal. Learners function within so many different social and cultural contexts that it makes sense to find out as much as we can about our students and their personal experiences in order to help them learn science.

1-4a Questions to Ask about Your Students

As we become teachers, we need to ask ourselves several important questions about our students. Wherever you live, whatever the particular types of diversity you encounter, answering these questions will help you to become a better teacher:

- *Who are my students?* This question refers to students' interests, concerns, hobbies, beliefs, and feelings about themselves and others.
- *What are their lives like?* This question encourages us to explore our students' family and home structures. For example, do they have siblings?

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Do both parents work outside the home? What do the students do after school? Do they have enough to eat? Who is at home with them in the evening?

- *Where do they live?* Is their home a room, an apartment, a private house? Is their block or neighborhood safe? Are there friends nearby to play with?
- *What interactions with nature are possible and attractive for them?* How does nature present itself in the neighborhood of your school and community? Are there trees and grass, mountains and plains, and rivers and valleys, or is there only concrete and cement where, even so, a dandelion grows? Are your students eager to go outside and explore nature, or are they more interested in virtual worlds on their computers?
- *How do events that shape my students' lives become opportunities to learn science?* In other words, what things happen in your students' daily lives that you could explore through a meaningful science experience? For instance, if your students live near a shore, you could observe the tides coming in and out as part of a science lesson.
- *How are my students' beliefs about the nature of science informed by their cultural backgrounds and their gender?* The ways we think about science and scientists are often based on where we live, how we grow up, whether we are male or female, and what cultural group we belong to. In Section 1-9, as you explore the socially constructed images of science and scientists, consider how students from different parts of the country, different cultural groups, and different nationalities might construct scientific images.
- *What are the learning differences among my students?* You may teach science in an inclusion classroom, where students with disabilities are educated alongside nondisabled students. When creating a science classroom that is truly inclusive, we need to ask ourselves if all the students can actively participate in the science lesson without any adaptations and achieve the same outcome. If not, we should make the necessary adaptations in the lesson.

1-4a Connecting Science to All Students

As you can see, learning to teach science involves a lot of learning about the students you will teach. Diverse classrooms are increasingly prevalent in the United States, and global migration has become commonplace, bringing more students from distant countries to our schools. Studies have shown that students with special needs, such as those with physical and/or learning disabilities, have a far greater chance to succeed academically and socially in the regular classroom than they do in a segregated classroom. Consequently, classes are intentionally organized to include students with broad ranges of learning and physical abilities as well as wide differences in cultural background. Typically, you can expect that your students may differ from one another by country of origin, native language, socioeconomic status, particular learning abilities, ethnicity, and gender, to name just a few characteristics.

Students can make meaning with whatever language and learning abilities they have available to them. As teachers who are engaging diverse groups of students in science experiences, we want to observe how they construct meaning *on their own terms*. It is our job to honor their processes and help them move forward to increase their understanding.

For example, a student who is not a native English speaker may completely understand the science experiences he or she is engaged in but may have

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difficulty expressing that knowledge in appropriate English terms. By encouraging the student in any way possible to communicate his or her meaning, we are honoring that child's process. When we do that, we say, in essence, "Your thinking is valued and appreciated." This prepares the ground for the student to continue learning.

In this book, you will learn how to build on your students' ideas in order to lead them to accurate understandings of the natural world. Helping students to develop their thinking in a structured way has been called *scaffolding*. We will see examples of that process later in the book. It is important to remember, however, that to build on students' ideas, you must learn what those ideas are. You begin by creating a learning environment in which all your students feel valued and able to make a contribution.

Constructivist teaching, as noted earlier, has the potential to give students more control over what they are learning. That is, instead of telling students what and how to think, we invite them to create their own ideas in ways that are congruent with who they are. For students with physical, emotional, or learning disabilities—who often have been discouraged in traditional science classrooms—this approach is especially vital. And accommodating students with special needs is compatible with the methods of constructivism: providing concrete activities, emphasizing the importance of process rather than the memorization of facts, promoting cooperative group experiences, and allowing the big ideas to emerge from specific contexts. As you teach, you will learn what accommodations your students with special needs require. The important point is to abandon the idea that only a certain type of student can be a good science learner. Teaching science is an engaging and empowering experience for you and all your students.

Students with special needs are not the only population that has not been encouraged to pursue traditional science. Often girls and people of color have been noticeably distanced from science; for many of them, the subject seems unrelated to their lives and disconnected from any contemporary meaning. Studies have shown that to encourage the science participation of girls and people of color, science teaching needs to be more concrete, to make connections to students' lived experiences, to engage students in social collaboration, and to consider topics of contemporary interest (Kahle & Meece, 1994; Koch, 2002; Sadker & Sadker, 1994; Sanders, Koch, & Urso, 1997). When we discuss scientific stereotypes in Section 1-9, it will become clear why boys have been identified with doing science more than girls. That is changing as researchers reveal to teachers how important it is to include all students actively in scientific work.

Differentiating Instruction When you ask yourself, "How can I be a really excellent science teacher?" part of the answer is holding out the expectation that all types of children can learn science. But the answer also involves finding ways to tailor your teaching to meet the needs of the different students in your class. Teachers regularly contend with the challenge of how to reach out to students who span the spectrum of learning readiness, personal interests, culturally shaped ways of seeing and speaking of the world, and experiences in that world. In Part Two of this textbook, you will read stories of teachers who, with varying resources available to them, are reaching out to students of different ages, backgrounds, and interests. In Chapter 12, we will also examine specific steps that are helpful when doing science with students who have a range of learning and physical disabilities.

differentiating instruction
Adapting instructional techniques to suit the needs of specific children or groups of children in a classroom.

Each time you do science a little differently to help a specific student or group of students in your class, you are **differentiating instruction**. Teachers who have differentiated classrooms are those "who strive to do whatever it takes

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to ensure that struggling and advanced learners, students with varied cultural heritages, and children with different background experiences all grow as much as they possibly can each day, each week, and throughout the year" (Tomlinson, 1999). You may think that such classrooms are not equitable because groups of students are receiving different types of experiences. However, the goal of equity is not equality of *treatment*; it is equality of *learning outcomes and achievement* that counts. To reach that goal, differentiating our instruction is a necessary and important technique.

Universal Design for Learning (UDL)
The attempt to design all products and environments, including learning environments, to be as accessible as possible by all people, regardless of age, ability, or situation.

In fact, differentiated instruction is becoming a default approach to planning science experiences. The approach known as **Universal Design for Learning (UDL)** aims to design all products and environments, including learning environments, to be as accessible as possible to all people, regardless of age, ability, or situation. When you read the science stories in this text, you will notice how elementary and middle school teachers set up science activities to allow for individual expression and creative participation by students with a wide range of backgrounds, interests, abilities, and learning styles.

Engaging Your Students As you will see, the same interventions that encourage more diverse participation in science classrooms also provide a better overall quality of instruction. Not only are those who were formerly marginalized in science more encouraged, but other students become more interested in the science experience as well. Hence, the national standards—and this textbook—support the idea that good science teaching can encourage the participation of all students. In other words, teaching to encourage diverse groups means good science teaching.

The important point is to *know* your students and *engage* them in activities that relate to their world.

For you as a teacher of science, engaging diverse groups of students in meaningful science learning experiences—and watching what happens as they each construct their own meanings from these activities—can be an exciting opportunity. It is reasonable to expect that, depending on their prior experiences, your students will come up with a wide range of ideas. Hence, the challenge is to mediate the differences and lead your students toward some accurate understandings of nature. This task, though not a simple one, can be exhilarating for you as well as your students.

1-5 The Role of Technology in Today's Science Teaching

Our lives have been transformed by the digital age in which we are living, and so have the methods of teaching and learning. For instance, just as communities of scientists work together electronically on a project, communities of science students may do the same. Their end product may be a joint experiment, tracking data collections in different localities, or producing a blog that disseminates information on an important and current scientific topic.

Because digital technologies are advancing so quickly, your students' involvement with them may reflect some of your own practices. How often do you text? Are you on Facebook? Twitter? Instagram? Snapchat? Can these technologies be used in the teaching and learning of science?

In educational settings, the term *technology* can mean practically anything—the chalkboard was once a stunning new invention—but in this book it will usually mean the seamless integration of computer software, Web-based resources, and other electronic devices (such as interactive whiteboards, digital video recorders, iPads, and video microscopes) to enhance students' understanding of a scientific concept.

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Technology in and of itself, however, cannot help students learn science. It is the students' *need* to use the technology that makes it part of the science experience. Suppose a class is tracking the monarch butterfly migration as the butterflies travel to and from Mexico each fall and spring. In this kind of investigation, they can use the Web for up-to-date information on the migration and for an animated map of the journey. Here, the technology becomes essential in the learning process, and students can even contribute to the scientific data with their own sightings of monarch butterflies.

The key point here is that the use of technology derives from a need to know more. Students turn to the computer or other technological device as a tool to help them actively construct their own knowledge. The technology is not foisted on the student for its own sake; rather, it acts as a needed and useful resource. Later in this text we will explore how handheld mobile technology in the form of a smartphone app helps sixth-grade students identify local trees.

1-4a Simulations and Interactive Websites

simulation
A computer program, virtual construction, or other procedure that imitates a real-world experience.

Today, many professional scientists study natural phenomena by using computer **simulations**, and students can do the same. Often these simulations imitate real-world activities that would be impossible to bring into the classroom. Say you want your students to understand the movements of planets in the solar system. Obviously you can't bring Mars and Venus to class, but you can use simulation software that shows the planets in motion and allows students to view the system from different positions. As another example, if you are teaching biology, your school system may not want to use dead animals, like frogs, for dissections, but you can turn to computer simulations of a frog dissection. In Net Frog, one of the most famous of such tools, students can perform a simulated dissection online.

Some websites are designed to pose a problem and then engage students in interactive manipulation of a simulated natural event. For example, some science websites allow students to set up a simulated experiment and draw conclusions from their observations. Thus, the students have the opportunity to engage in science processes by manipulating the keys on a computer keyboard or by using their tablets or smartphones. One such site allows students to vary the length, tension, and thickness of a simulated violin string in order to explore the effects these three properties have on the pitch of the sound created when the string is plucked. Using this program, third-grade students have the opportunity to manipulate the three variables in any way they choose.

1-4a Tools for Expression

In addition to simple word processing, computer technology allows students to display their understanding of science ideas by making multimedia presentations. In our example of the simulated violin string, the student might create PowerPoint slides or a video to present visual and audio illustrations of several strings producing different types of sounds depending on their length, thickness, and tension.

1-5c A Means of Collaboration

The most social part of making meaning in science—collaboration or person-to-person communication—is facilitated by electronic telecommunication. For their own classes, teachers can create focused discussions online through the use of software designed for this purpose. You may already have

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participated in such reflective discussions using Blackboard courseware or a similar tool in your college classes. These technology-supported conversations can help students refine their thinking, and they help build a sense that everyone is working together in a learning community. By putting digital technology to educational use, you can make learning more relevant to the students' daily lives.

As you explore technological tools for science learning, remember to ask yourself about your students and their lives. You may teach in a community where high-tech devices are commonplace, both at home and at school. Or you may teach in a place where students rarely have access to computers at home. Many educators have used the term **digital divide** to refer to the gap between those with easy access to digital technologies and those without. This type of information about your students is important as you plan for meaningful science experiences. If your students do not have ready access to the Internet, you may need to take them to a local library or government facility.

digital divide
The gap between those with easy access to digital technologies and those without.

Even when students have plenty of opportunities to use technology, there can be important differences among individuals and groups. In particular, many studies have been done about gender differences in the use of computers. At first, educators worried that girls spent less time with computers than boys, both at school and at home. These concerns have mostly faded as computers have become more prevalent everywhere (DeBell & Chapman, 2003), but some gender differences in technology use still seem to exist:

- Girls' approach to the use of instructional technology is more collaborative, whereas boys tend to be competitive (Rajagopal & Bojin, 2003).
- Overall, boys use computers in different ways than girls do; the boys tend to "mess around" more, to see what they can make the computer do. In the process, the boys acquire a lot of know-how (Abbott et al., 2007), and their experience helps them in science activities that require computer use.

If such differences exist in your classroom, you will want to take steps to put girls and boys on an equal footing:

- Monitor all students' use of technology for learning science.
- Review science software and science games for their appeal to both genders.
- Encourage girls to explore all the ways in which technology can help them learn.

No matter where you live or how digital technologies have pervaded your own life, you will find the technology connections in this book useful. True to the spirit of constructivism, I invite you to explore these connections and to develop your own ideas about using technology for meaningful science.

1-6 Locating Your Scientific Self

Many new teachers don't think of themselves as scientists. They often regard science as a subject beyond their grasp. This uneasiness leads them to rely on external authorities in science rather than looking inside themselves and cultivating their own scientific approach. Yet, as I mentioned at the beginning of this chapter, there is a budding scientist in everyone, and the task for a new teacher is to rediscover his or her scientific instincts and develop them. Think about that as you read the following story about a school science workshop for new teachers.

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SCIENCE STORY

Science Story

The science workshop at the state school science conference was titled "Have Fun with Science." In parentheses the announcement said, "New teachers especially welcome." It was a well-attended workshop. There were fifty elementary schoolteachers gathered in a lab room at the local state college. In front of us stood Rose, a gray-haired woman who had placed bottles of different sizes, colored liquids, yellow balloons, and pins at the head lab table.

To begin, Rose pulled two yellow balloons out of a bag and asked us to notice the ways in which they were the same. The teacher audience chimed in with, "Same color, same shape, same size." "They are both deflated," one participant shouted. Someone in the back approached the front table and asked if she could smell the balloons. "Hmm," she mused, "they smell rubbery." Someone in the front shouted, "If you blow them up, they will both be round." Everyone seemed quite engaged with these two ordinary yellow balloons.

Rose inflated both balloons so that they were just about the same size. On her worktable, she had a small bottle of a blue liquid and a box of straight pins. As she held a straight pin to the side of the first yellow balloon, she remarked, "Of course, we know what will happen when we strike the balloon with this pin." With that remark, she popped the balloon.

Taking the next balloon, she dipped the same pin into her bottle of blue liquid and said, "Now, what do you think will happen if we stick this balloon with the pin that I have dipped in my blue liquid?" The audience was unsure, but the general feeling was that the balloon would pop as the first one did. Rose stuck the blue-liquid-coated pin into the end of the second yellow balloon, and there it sat. With the pin stuck halfway into the balloon, the balloon did not pop!

"Now," asked Rose, "why do you suppose *this* yellow balloon did not pop as the first one did?" Several teachers volunteered responses. "The blue liquid," one teacher offered, "sealed the hole the pin was making as it went into the balloon." Another said, "The blue liquid made the pin so slick that it just slid into the balloon without making a hole."

"You have made some interesting comments. Any other ideas?" Rose looked around the room.

One teacher, named Susan, sitting toward the back of the room, sheepishly raised her hand. "I thought, as I was watching you," Susan remarked, "that you placed the pin in a different part of the second yellow balloon. You placed the pin in the end of the balloon this time, but the first time you placed it in the side of the balloon."

"What about the blue liquid?" Rose asked.

"Well," Susan responded, "I don't think it has anything to do with it."

Before Rose could comment, I remember thinking how observant Susan had been. I was impressed with her ability to offer an explanation that was so clearly unrelated to the blue liquid.

Rose asked, "How can we test this possibility—that it was where I placed the pin in the second balloon and that it had nothing to do with the blue liquid?" One teacher suggested that she take a pin, dip it in the blue liquid, and place it in the side of the balloon. Another participant suggested that she take a pin and, without dipping it in the blue liquid, place it in the end of the balloon.

Responding to these ideas, Rose inflated two more yellow balloons, identical to the first two. She placed a pin in the blue liquid and into the side of the first yellow balloon. *It popped!* Then she placed a pin without any blue liquid into the end of the second yellow balloon. It did *not* pop! Everyone sat back, apparently surprised yet again. Everyone, that is, except Susan.

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1-7 Thinking Scientifically

Let's think about how the teachers in Rose's workshop behaved. Most of them were ordinary classroom teachers, and some were new to the profession. They were not scientific experts by any means. Nevertheless, they were behaving scientifically by:

Making observations of the yellow balloons. *Observations* include all our perceptions of an object or an event, using as many senses as we can and offering possible explanations for why the second balloon did not pop. These possible explanations are called *inferences*. Inferences are based on our observations and sometimes lead us to set up further investigations. Each time the teachers came up with their own ideas and thought about the reasons for the events, they were behaving like scientists. While most of the teachers in the workshop were openly expressing their observations and inferences, one teacher, Susan, expressed a contradiction—a challenge—to Rose, the person directing the workshop and the one apparent "scientific authority" in the room. Rose made it appear that the blue liquid was the reason the balloon did not pop. In a way, she was tricking the teachers. Susan challenged this idea, and by doing so came up with the correct analysis of the situation—that it was where the pin was placed, not the blue liquid, that made the difference. Susan's daring is especially important here. Many times, scientific investigations seem beyond our grasp, and for that reason scientific authority goes unchallenged. But once we begin to rely on our own perceptions, we may find that the science in question isn't as obscure as it first seemed. The balloon story demonstrates how important it is to trust your own observations and inferences in order to find out more about the world. In this way, you will get in touch with your scientific self and become *your own source* of scientific expertise.

1. By suggesting that the position of the pin had something to do with the balloon's not popping, Susan was **engaging in argument from evidence**.
2. After Susan offered the hypothesis that it was the position of the pin, the teachers took the next step: testing it. They were **carrying out an investigation**. Rose, following the teachers' suggestions, tested Susan's hypothesis by planning a specific test procedure and then carrying it out. These steps distinguish science from other forms of creative human endeavor. Testing ideas by planning investigations and carrying them out is a critical part of the work of scientists.
3. Teachers in this workshop engaged in a variety of scientific activities. By observing, inferring, forming a hypothesis, testing it, and, most of all, *trusting their own judgment*, they behaved very much like scientists. Ultimately they came to understand that the balloon is thickest at its rounded end and therefore has the least tension there. A pin placed there will not pop the balloon. If you're doubtful, try the experiment yourself. Make your own observations and trust your judgment. This is part of developing a set of attitudes that help you do science. You can challenge authority and trust your own experience.

In the next section, we'll take the next step in locating your scientific self by exploring in more detail the kinds of ideas that teachers, and other people in our society, commonly hold about scientists. As you read, remember the story about the pin, the balloon, and the mysterious blue liquid. By the way, Rose finally admitted that the blue liquid was—did you guess?—just blue food coloring and water.

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1-8 Beliefs about Science: We Teach Who We Are

You may be wondering, "Why all this fuss about the scientist within and locating your scientific self? If it's just a matter of trusting my own judgment, I can do that."

There is more to it than that, however. For one thing, looking inward helps you recognize your own feelings about science. Your feelings about the subject of science help to shape your attitudes toward it, and both your feelings and attitudes greatly affect the way you teach science in the classroom. One early study indicated that teachers' negative attitudes toward science made them reluctant to teach science; sometimes, even, they avoided teaching it (Perkes, 1975). Additional research has consistently shown that negative attitudes toward science create obstacles to the effective teaching of science (Koballa & Crawley, 1985; Shrigley, 1983, 1990; Smith & Gess-Newsome, 2004). Let's explore some reasons why this is true.

1-8a Your Feelings Show

It is almost impossible to mask negative feelings and attitudes about science when you are dealing with your students. Students have an uncanny ability to see below the surface and get to the heart of their teacher's reactions, even when the teacher is a terrific actor and believes he or she is hiding the truth. Authenticity "outs itself"! (Figure 1.3).

1-8b Teacher Attitudes Affect Students' Attitudes

Many studies indicate that teachers' feelings and attitudes about science affect their students' feelings and attitudes. For instance, one study that used personal narratives to explore students' attitudes concluded that the scientific experiences that students reported as positive were clearly influenced by teachers whose attitudes toward science had been very positive (Koch, 1990). In other words, teachers who have a positive outlook toward science tend to instill that outlook in their students. We also know that students' positive feelings are

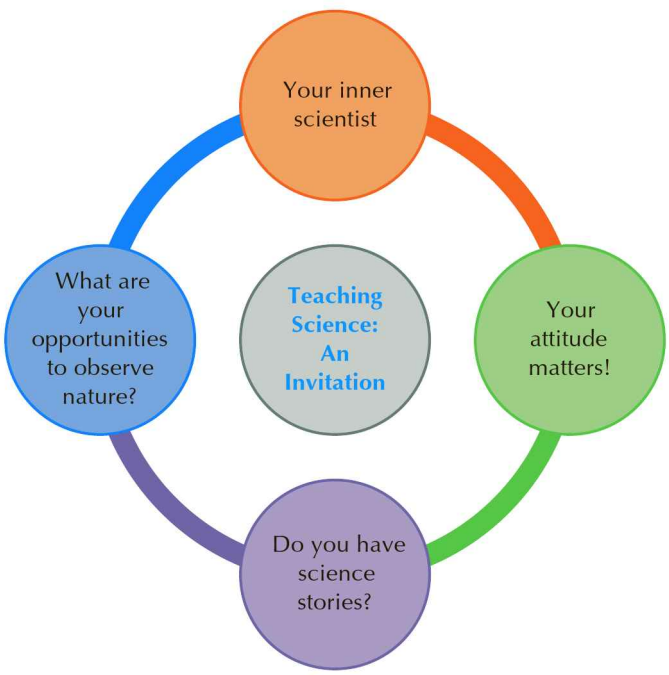

FIGURE 1.3 Teaching science: an invitation

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related to their performance in the subject area (Stickelmaier, 2007). In fact, interviews with scientists often reveal that they had inspirational teachers whose love of science motivated them to pursue scientific careers (Koch, 1993).

Unfortunately, the reverse is also true. Teachers with negative outlooks toward science often inadvertently discourage their students from pursuing scientific interests. As early as 1969, a study found that elementary school teachers' negative attitudes toward science were passed on to their students (Walberg, 1969). Overall, the literature reveals that the role of the teacher is vital in shaping students' attitudes and interest in science (Jones & Levin, 1994; Tosun, 2000).

As we noted earlier in the chapter, whatever subject you teach, you are always, in a sense, teaching *who you are*. This means that your authentic self is visible and vulnerable in your classroom, and it has a great effect on your students.

The feature called "Your Attitude toward Science" offers a simple questionnaire that you can use to begin understanding your own attitudes. The exercises in the rest of this chapter will also help you acknowledge your innermost

Your Attitude Toward Science

In our context, "attitude toward science" can be defined as favorable or unfavorable feelings about science as a school subject (Morrell & Lederman, 1998). Your attitude has probably been influenced by your previous science experiences in school and outside of school, the types of science courses you have taken, your gender, and various social influences—not to mention the attitudes of your own teachers. Your attitude toward science is also connected to your personal beliefs and your sense of yourself as a science learner. Those who have negative views of their own competence and low expectations for their success are more anxious in learning contexts and more fearful of revealing their ignorance (Abu-Hilal, 2000; Harter, 1992; Hembree, 1988).

Explore your attitude toward science with the following survey. Indicate the accurate number for yourself next to each of the statements below:

(1) Strongly Agree (2) Agree (3) No Opinion (4) Disagree (5) Strongly Disagree

____ 1. Science is useful for the problems of everyday life.
____ 2. Science is something that I enjoy very much.
____ 3. I do not do very well in science.
____ 4. Doing science labs or hands-on activities is fun.
____ 5. I feel comfortable in a science class.
____ 6. There is little need for science in most of today's jobs.
____ 7. Science is easy for me.
____ 8. When I hear the word "science," I have a feeling of dislike.
____ 9. I do not like anything about science.
____10. I feel tense when someone talks to me about science.
____11. It is important to know science in order to get a good job.
____12. I would like a job that does not use any science.
____13. I enjoy talking to other people about science.
____14. I enjoy watching a science program on television.
____15. I am good at science labs and hands-on activities.
____16. You can get along perfectly well in everyday life without science.
____17. Working with science upsets me.
____18. It makes me nervous to even think about doing science.
____19. It scares me to have to take a science class.
____20. I have a good feeling toward science.

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What have you learned about your attitude toward science? How will this help you to prepare to teach science?

Save your score until the end of the book and then take this survey again!

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feelings about science. As you engage in these activities, you will learn more about your scientific self. If you were "turned off" to science in secondary school and college, this chapter should help you become more comfortable with it. The important thing is to acknowledge your feelings and consider "making friends" with science as one of the goals of locating your scientific self.

1-9 Who Is a Scientist? Stereotype versus Reality

Who do you think is a working scientist? What does a scientist look like? To begin discovering your scientific self, let's explore how you conceive of scientists.

1-9a Drawing a Scientist

We've reached the point in the chapter where you will need to close this book. But first get a piece of paper and a pencil and find a firm writing surface. Set this book aside, and sketch a picture of what you think a scientist might look like. When you have completed the drawing, open the book again to this spot. If you are like most people, your scientist drawing will show a white male with one or more of the following characteristics: wild hair, eyeglasses, a white lab coat, a pocket protector, and some bubbling flasks (Figure 1.4). Studies reveal that both students and teachers frequently draw this popular image of the scientist (Barman, 1999; Fort & Varney, 1989). Of course, this image is a stereotype that exaggerates what real scientists look like. This stereotype is reinforced by the images of scientists that we see in cartoons, movies, magazines, and the popular press. Such stereotypes become part of our belief systems and influence our future behavior. All too often, they limit what we do and think.

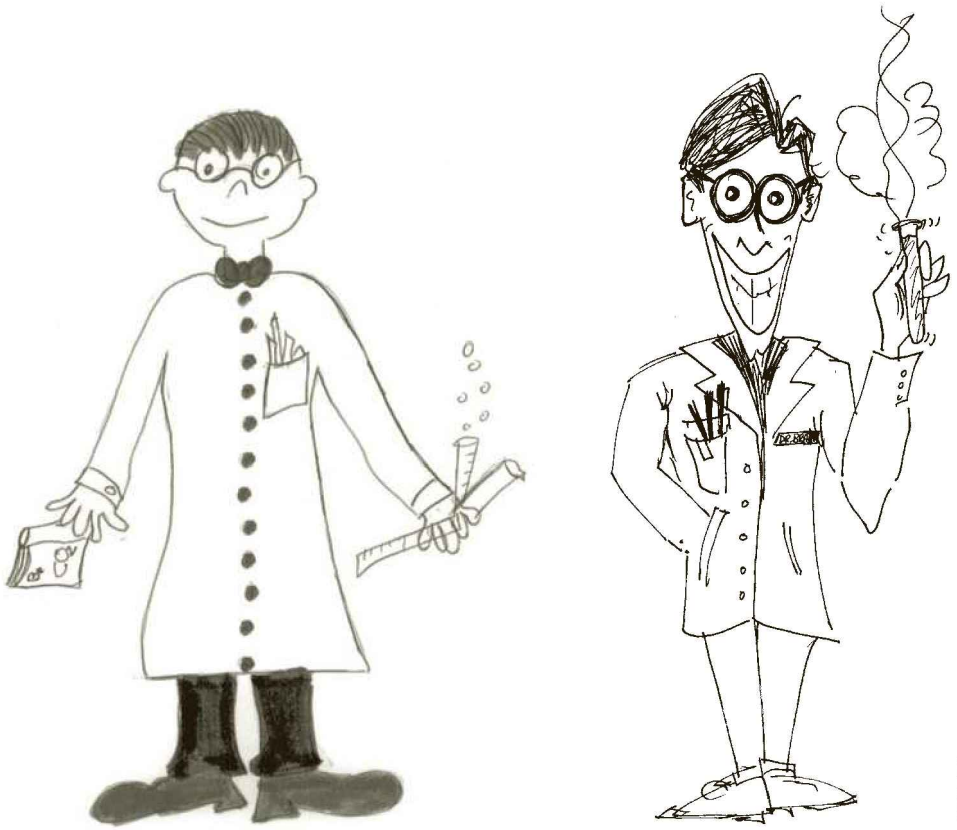

FIGURE 1.4 Responses by two preservice teachers to the assignment "Draw a scientist"

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Third Graders Draw Scientists Not long ago, two third-grade teachers in a local elementary school were interested in exploring their students' beliefs about scientists. Distributing crayons and drawing paper, they asked each student to draw a picture of a scientist and describe what the scientist was doing. The thirty-nine students' drawings contained thirty-one men and eight women. Further, of the thirty-one male scientists, twenty-five had beards and messy hairstyles.

One boy added a bubble quote for his scientist that said, "I'm crazy." Another third-grade boy described his scientist as follows: "He is inventing a monster. He painted his face green." Still another boy wrote, "My scientist makes all kinds of poisons. He is a weird person." Another caption on the bottom of a drawing said, "Dr. Strangemind," and on the back the student explained, "He does strange things like blow up things and other crazy stuff." Many of the children described their scientists as "blowing things up," "acting crazy" or "goofy," or working with "a lot of potions" (see the typical student drawings in Figure 1.5).

FIGURE 1.5 Responses by three elementary school children to the assignment "Draw a scientist." Compare these to the teachers' drawings in Figure 1.4

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FIGURE 1.5 (*continued*)

You can see that most of these third graders, young as they were, had already internalized the stereotyped image of the scientist. To understand why this is important, ask yourself the following questions:

- Who is omitted in this stereotype?
- Does the type of person represented in the stereotype reflect the makeup of any class you have recently seen?
- If the students in a typical classroom were omitted by the stereotype, how would that make them feel about science?

You may suppose that stereotypes about scientists diminish as children mature. In fact, however, a study of over 1,500 students in grades K–8 revealed that students' drawings of scientists became more stereotypical as the students grew older. These students drew mostly white male scientists, suggesting that the stereotype persists despite recent changes in curriculum materials (Barman, 1999).

Stereotypes Can Be Discouraging As you may suspect, the scientist stereotype can discourage individuals who are other than white and male from seeing themselves as truly scientific. Some of the consequences are obvious. For example, until recently, substantially fewer females enrolled in advanced science courses than did males, beginning in high school and continuing through college. Thankfully, this gap is closing in a number of scientific fields. Among college undergraduates, four of the major sciences—geology, life sciences, chemistry, and astronomy—are now at least half populated with women (National Center for Science and Engineering Statistics, 2015). Yet the gender gap persists in other branches of science, notably in physical sciences like physics and engineering. The gender gap persists despite many types of interventions designed to encourage girls and young women to participate in science (Koch, Polnick, & Irby, 2014). The largely female elementary and middle school population of teachers can contribute to gender parity by modeling the joy of discovery and the excitement of doing science. Teachers as role models go a long way toward helping students feel capable and competent in science.

Stereotyping is a complex issue, but the way in which we conceptualize "who does science" certainly contributes to the problem. One primary school teacher holds a gigantic mirror up to her students whenever the question of who can be a scientist emerges. This helps the students envisage themselves in the role of the scientist, ensuring that they will feel entitled to that role as they explore natural phenomena in their own classrooms.

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Reflecting on Your Drawing With this discussion in mind, go back and look at your own sketch of a scientist. What exactly did you draw? Who is your scientist? Is the person you drew similar to yourself or very different? What does this tell you about your feelings and attitudes toward science?

Keep the draw-a-scientist activity in mind not only while you read this book but when you teach science. For both students and adults, the activity can be useful in exploring the implications of the scientist stereotype. You may want to try it with your own students.

Women have always done science, and among them are Nobel laureates and world-class scientists whose lives and work often inspire others to follow. The same is true for African Americans, Latinos, and members of many other minority groups. Hearing their stories teaches our students that scientific study is and needs to be a collaborative effort by men and women of all races and ethnicities. Naturally, if people had more contact with real scientists, they would observe much more diversity than the stereotype allows.

1-10 Your Science Autobiography

As far back as the turn of the twentieth century, the philosopher John Dewey spoke of the need to educate future teachers in ways of thinking about teaching, not just in the technical aspects of teaching (Dewey, 1904). Since then, the image of the teacher has frequently shifted back and forth between two poles. On one hand, the teacher is seen as a technical expert who has acquired and can execute a series of specific skills related to teaching. On the other hand, the teacher is seen as Dewey's type of *reflective practitioner*, someone who has the capacity to think critically about her or his work. Actually, both facets of teaching are important. Certainly there are particular techniques for teaching and there are ways of thinking that help teachers decide which techniques are preferable in any given teaching situation.

The term *reflection*, when applied to teachers, generally refers to a process in which they explore their own teaching practice, asking themselves important questions about their interactions with students as well as the curriculum. **Reflective teachers** have the capacity to think about their roles as teachers from the standpoint of who they are, who their students are, and what they hope to accomplish. Reflective teachers are very conscious of their feelings about their school environment, their students, and their teaching situation. They are able to recognize potential and existing problems and explore multiple approaches to solutions. To put it another way, a reflective practitioner is always looking inward and asking, "How am I doing?"

reflective teacher
A teacher who thinks deeply about his or her teaching practices, the needs and identities of the students, and what the teaching is intended to accomplish.

Research shows that a deliberate, conscious, inward look at teaching and learning can promote your professional development as a teacher. For one thing, it helps you identify areas that you can research and explore. A foremost researcher in the field of reflective practice, Donald Schon (1983), remarks that the reflective teacher constructs her or his practice. What he means by this is that instead of following a list of rules, the reflective teacher explores the classroom environment and creates or modifies her or his own teaching methods to establish new and better contexts for learning. As so much of your professional life will involve personal reflection, this is a good time to begin to look inward. In this section, you are asked to reflect on your past science experiences. Whether you know it or not, your own experiences with science in school helped to shape your beliefs about teaching and learning science. Your personal reflections hold the key to uncovering these tacitly held beliefs about science. They also provide the opportunity to begin to modify these beliefs if you feel that is necessary.

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1-10a Writing Your Science Autobiography

Time to close this book again! First, follow these directions:

1. Take out a fresh piece of paper and a pen or turn on your computer.
2. Think back to your most vivid memories of being a science student, up to and including your college experiences.
3. Are you ready now? You're going to write your own science autobiography.

science autobiography
A personal description of one's experience with science, in or out of school.

This is a writing exercise in which you explore your feelings about science. Your **science autobiography** should be a *personal* description of your experience with science, in or out of school, through teachers, friends, family, museums, magazines, and other sources. The following questions can help you to think about this task:

- When you look back at your science education, what do you see?
- How much science did you study in school?
- Did you like science? Hate it? Did you ever even think about it?
- What personal experiences with school science, scientists, science in the media, and science teachers stand out for you?

Teachers who have written their science autobiographies often begin by saying that at first they could not remember anything. Then they took a few moments to look back and consider their science educations grade by grade, or year by year, and their stories were reclaimed. If you're having trouble getting started, it may help you to read the accompanying feature, "Excerpts from Preservice Teachers' Science Autobiographies."

Write candidly and freely about your evolving experiences with science and your beliefs about it. It does not matter how limited or extensive your experiences are, only that you describe them. There is no prescribed length or format for your science autobiography. It is your story and needs to reflect your experiences.

Excerpts from Preservice Teachers' Science Autobiographies

The following passages, drawn from the science autobiographies of five preservice teachers, indicate some of the feelings that teachers have expressed about their experiences with science.

Albert Einstein I am not. Even as a young child, I was not enthusiastic about science. Although I was a very good student and I always excelled in my science classes, including honors chemistry and biology in high school, I was never excited about doing dissections or experiments. When I was given the option in senior year to take advanced placement science courses, or just drop science, I quickly stopped taking science altogether. . . .

When I reflect on my past experiences with science, two words come to mind: "Not interested." Then I entered fourth grade, and science came alive. My outlook on science was much brighter, thanks to the efforts of Mrs. M, who helped me to feel confident by giving the class activities that we could make our own judgments about. . . .

When I think of science, I can only remember how much I dreaded it. It was boring, rote memorization that never seemed to end. I found it impersonal. Everything that was science came straight from the textbook. You were not expected to understand it, just to know it. . . .

When I was in college, I finally had a good science experience. It was in college biology. For the first time a teacher related the ideas we were learning about to events in the students' experiences. He also allowed the students the freedom to explore their own questions. . . .

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The very process of writing a science autobiography helps us to examine our remembered experiences. But that is only the beginning. By reflecting on your story, you can gain a deeper understanding of how your experiences shaped your current thinking about science and your attitudes toward science. We know that teachers bring these beliefs—formed by their direct experiences with science in school, the people they meet who work in science, and the publicity science receives—to their teaching practice. Chances are that you will too. The challenge is to reflect on what you have written and make a conscious decision about how these remembered science experiences will influence your behavior as a teacher.

Begin your reflection now. You may want to start a new chapter in your science autobiography at this time. Ask yourself, "Why did I remember some stories and not others? How did these stories affect my current feelings about science and the prospect of teaching science?" You may already be starting to see science in a different light as you find your "scientist within" and consider teaching science in elementary or middle school. In the next section, you can try another method for locating your scientific self.

As you examine the circle of ideas that relates to Teaching Science: An Invitation (see Figure 1.3), you can see that one of the circles asks about your opportunities to observe nature. This is connected to your inner scientist. Although you may be asked to keep reflective journals about the feelings and events that have engaged you in your journey toward becoming a teacher, keeping a science journal is a bit different as it invites you to explore nature and find your inner scientist.

1-11 Keeping a Science Journal

Personal journals are important for developing your skills at looking inward. The activity of writing in your journal and reflecting on what you have written becomes your own process of meaning making, and this is an important tool for your professional development.

science journal
A personal journal in which the writer focuses on nature and natural events in his or her daily experiences.

A **science journal,** as we use the term here, is a personal journal in which the focus of your attention is nature and natural events you encounter in your daily experiences. Science can be thought of simply as a way of knowing your natural world. Therefore, a science journal contains your observations of and questions about nature.

Recently scientists have been exploring the positive effects of plants, sunshine, and even soil on adults' health. Scientists use the term *biophilia* to explain why connecting with nature feels good. It refers to the innate affinity humans have for other living things (Jones, 2008). In this digital age, when Americans spend 90 percent of their time indoors, your science journal can become a way to put your biophilia into action. Making observations of nature and recording them in your journal will give you an opportunity to explore nature and feel good while doing it! Learning how to keep a science journal also helps you develop the habit of questioning what you see and discovering the answers to those questions. For all these reasons, science journals are a way of contacting your scientific self.

Besides direct observations, science journals can contain items about science in the news or science that you see in a classroom. You can write about a science show you saw on television or a newspaper story about a recent scientific breakthrough. If you have observed science in a school or classroom, write about it. What did you think of it?

1-10a How Do I Keep a Science Journal?

You may keep your science journal in any format: online, on your tablets, smartphones, computers, or in a written form. Try to make entries in your journal on a fairly regular basis—about two or three times a week.

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Remember that your science journal can encourage you to ask your own questions. If you observe something that you do not understand, write about it. A science journal may contain your mental wanderings and scientific wonderings. You may also think of a science journal as a "log" in which you record the natural events that capture your curiosity and take you by surprise.

1-11b A Bird Story: Sample Entries from a Science Journal

The following excerpts from my own journal illustrate a type of story that sometimes emerges in science journals. This is the almost-daily log of a bird-watching experience I had in my own backyard. The experience took me by surprise, and I enjoyed writing about it. The geographic setting is a densely treed suburban area outside of New York City. Notice that I did not know how to explain everything I saw; I recorded my questions as well as my observations.

Tuesday: I never noticed the hollow in the middle of the trunk of the low-lying tree in the backyard. Imagine my surprise today when, as I glanced through the dining room window, I saw a bird fly right out of the tree! I wandered over to the tree trunk and peeked inside the hollowed-out area. I counted eight small white oval eggs. Each egg seemed to be about 4 cm long. The baby birds will soon be hatching, I think.

I wonder why the eggs are white. Wouldn't it be better if they were a dark color, for camouflage?

Tuesday [two weeks later]: Well, it has been two weeks, and the mother bird continues to fly into and out of the tree periodically. Sometimes when I glance into the hole, I can see her just sitting there. Yesterday, when I went to pay her my usual visit, she flew out just before I reached the tree. I leaned over to peek at the little eggs, but they were gone! In their place were several tiny birds, their necks extended upward and their beaks wide open. They made soft, small chirping noises that seemed clearly to say, "Feed me."

Quietly I stared at them, and then, fearing that the mother bird would return at any moment, I walked away. Now I am wondering what type of bird this is. It's not one that I recognize.

Wednesday: This morning I ran out to the hollow in the tree. The sun was shining at just the right angle, into the hole in the tree trunk. The mother bird had just flown away, and when I peeked in, I counted at least eight pink baby birds, eyes closed, with no feathers. They really do look brand new and fragile. I wondered where the mother bird had gone and how long she would leave her hatchlings alone.

An hour later, I returned for another glance, and as I looked down into the hole, the mother bird looked right back up at me. Was I surprised! I quickly walked away. But I've noticed that she has a pointed beak and brown feathers, and I could see a black marking at her neck, as though she had on a collar. When she flies off, I can see white feathers on her tail. She's a largish bird. I must find my bird book and identify her.

Sunday, late at night: I had to leave on Friday for a short trip, and I hated to miss the progress of the hatchlings. I've observed that the mother bird sits on the hatchlings often. Her frequent feeding trips take her into and out of the hollow in the tree many times a day.

Tonight I arrived home at midnight, eager to see how the baby birds were doing. I took a flashlight and went outside. I placed the flashlight on the ground so I could get close enough to the tree to peek without alarming the birds with the bright light. As I approached the tree, I noticed the mother bird perched inside, looking straight out of the hole, which is several inches above the nest. Her clawed feet must have been clinging to the inside of the tree. I didn't see the hatchlings tonight—I decided to go back inside without disturbing the mother.

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Anthony Mercieca/Science Source

PHOTO 1.3 A mother flicker guarding her hatchlings at the hidden nest in the hollow of a backyard tree. Notice the black marking at neck and the ever-hungry hatchlings!

Monday: The hatchlings are still there, a little bigger now. And I've found my field guide to the birds. Combing through the pictures, I spotted several birds that seem to look like the mother bird. She's a little like a catbird and a little like a mockingbird with her white feathers under her tail. But then I found her—and her black necklace. She's a northern flicker; I'm sure of it. I was so excited to identify her (see Photo 1.3).

Wednesday: It has been two days now since I last saw the mother bird. I look often for her, making her frequent runs into and out of the nest, and I'm getting worried. Last night I woke up in the middle of the night and went out to the tree with my flashlight, but there was no sign of her at her guard post in the hollow of the tree.

Thursday night: This was the third night, and still no mother bird. I made my decision. The eight baby hatchlings would starve if I didn't do something! I prepared a deep, small cardboard box with wood chips and shreds of newspapers. I was nervous as I reached down into the hollow of the tree to lift the baby birds out, one at a time. Oh my, I thought, they're down much deeper than it appeared. It took almost the entire length of my arm to touch one. Slowly, I grabbed the bottom of one bird and then another, and after ten minutes, I had lifted all eight hatchlings from their nest. They felt very warm to the touch.

Earlier today, before finally deciding to remove the birds, I had contacted the owner of the local pet store to learn what he recommended for flicker hatchlings. I drove over there to buy some food and a small syringe for feeding them. Tonight when I put them in the box, I was ready. Using warm water, I mixed the food and filled the syringe. They were very hungry. They nestled together in a corner of the box on a table in my garage. I'm going to get up every two hours tonight to feed them.

Friday morning: It's not easy getting up every two hours to feed birds. But I'm glad I did it.

At 8 A.M. I called the local bird sanctuary and asked if I could bring the birds in for care. I got directions for finding the place. Mary, the director, turned out to be

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kind and caring. She immediately placed a small heating pad under the hatchlings inside their box. Using her fingers, she put solid, moist food down their throats with her fingers, and she showed me how their necks swell as the food goes down. The bulge in the neck shows which one has been fed. "My, what beautiful flickers we have here," she said. "Where is the mother?" I explained to her that I have not seen the mother bird for days. She said that if the mother were still around, I surely would have seen her as I was removing the babies from the tree. She said it was important to feed them often and that the mother bird would have fed them at least every two hours. So I guess my feeding them last night was the right thing to do.

As I left the bird sanctuary, glad to know that the birds were in good hands, Mary invited me back any time to visit with them. When I returned home, I was surprised to notice how lonely I felt after my days of observing the activity in the hollow of the tree. Now the tree is empty.

Friday evening: I've been realizing that the process of observing nature requires an investment of time and leads to an attachment to your objects of study. I really became *attached* to that bird family, and now that they're gone, I miss the activity as well as the birds themselves. I'm even slightly miffed that I won't have to get up every two hours tonight to feed birds!

When you spend time making observations of nature, you become invested in that experience. This afternoon I looked around for something else to study, but nothing caught my eye. I still wonder what has happened to the mother bird. Actually, I'm terrified that she'll return to the tree to find her hatchlings gone!

Monday: I returned to the bird sanctuary today to visit the hatchlings. They were still in the box I had prepared for them, and they seemed much bigger. Their feathers are appearing—black feathers emerging around their necks. I fed them with my fingers and chatted with Mary. In a week, she said, she'll place them in an indoor cage, so they can flutter around. Then they'll be removed to an outdoor cage, where they can practice their flying before being released into the wild.

Mary assured me that they are in very good shape and will be fine adult birds before long. I asked about something else that's been on my mind—why the eggs were white rather than colored for camouflage. She explained that because these birds lay eggs in hidden nests, they don't need camouflage.

Before I left the sanctuary, Mary told me that another flicker may choose to lay eggs in the same tree hollow. Funny—my heart soared! I'll welcome the chance to observe another bird family. I'm going to watch this tree (that I barely knew existed a few weeks ago), and I hope nature will give me another opportunity.

1-11b Some Guidelines for Your Own Science Journal

Keeping your own science journal means taking notice of your natural surroundings. It also invites you to develop a keen ear and eye for news stories that involve scientific matters. Anything can be grist for the mill. Keep the following reminders handy as you begin your journal:

- All of your observations are important. No observation is silly or too simple.
- All of your questions have value; collect them in your journal.
- Note the date and time of all your entries. This information can be helpful later if you want to go back and look for a pattern or connections.
- Entries in your journal can be of any length.
- Watch for interesting science shows on television.
- Make use of any opportunities to find out what other people are thinking about natural events.
- Have fun and write freely.

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1-10a Your Inner Scientist

The activities in this chapter have all been designed as tools to aid your self-exploration. They will help you to locate your scientific self through personal reflection and the exploration of science and scientists. From Rose's yellow balloons to your scientist drawing and science autobiography, they all concern the question, "What do *you* think about science, and how can you feel most comfortable with it?" Remember, your "inner scientist" will ultimately be visible to your students. I hope that this book will help you to approach the teaching of science with pleasure and confidence.

1-12 Becoming a Science Teacher

Teaching science may seem daunting at first. Science is often the one area that was neglected in our own early schooling. When you chose your profession, it is doubtful that you pictured yourself planning "science lessons." Please know that you are not alone. Some future teachers are even shocked when they learn that, indeed, science is an integral part of the school experience in the earliest grades.

Teaching gives you an extraordinary opportunity to be a lifelong learner. You will be constantly learning about your students, about yourself, and about new ideas. In particular, doing science with students enables you to become a special kind of explorer and meaning seeker. By that I mean that your own honest observations and experiences of nature are an important part of doing science with students. Although this is not a "how-to" book with step-by-step instructions on teaching science, I hope it is a how-to-think book—one that will help you to think about doing science in ways that bring both you and your students knowledge, pleasure, and confidence.

Resources

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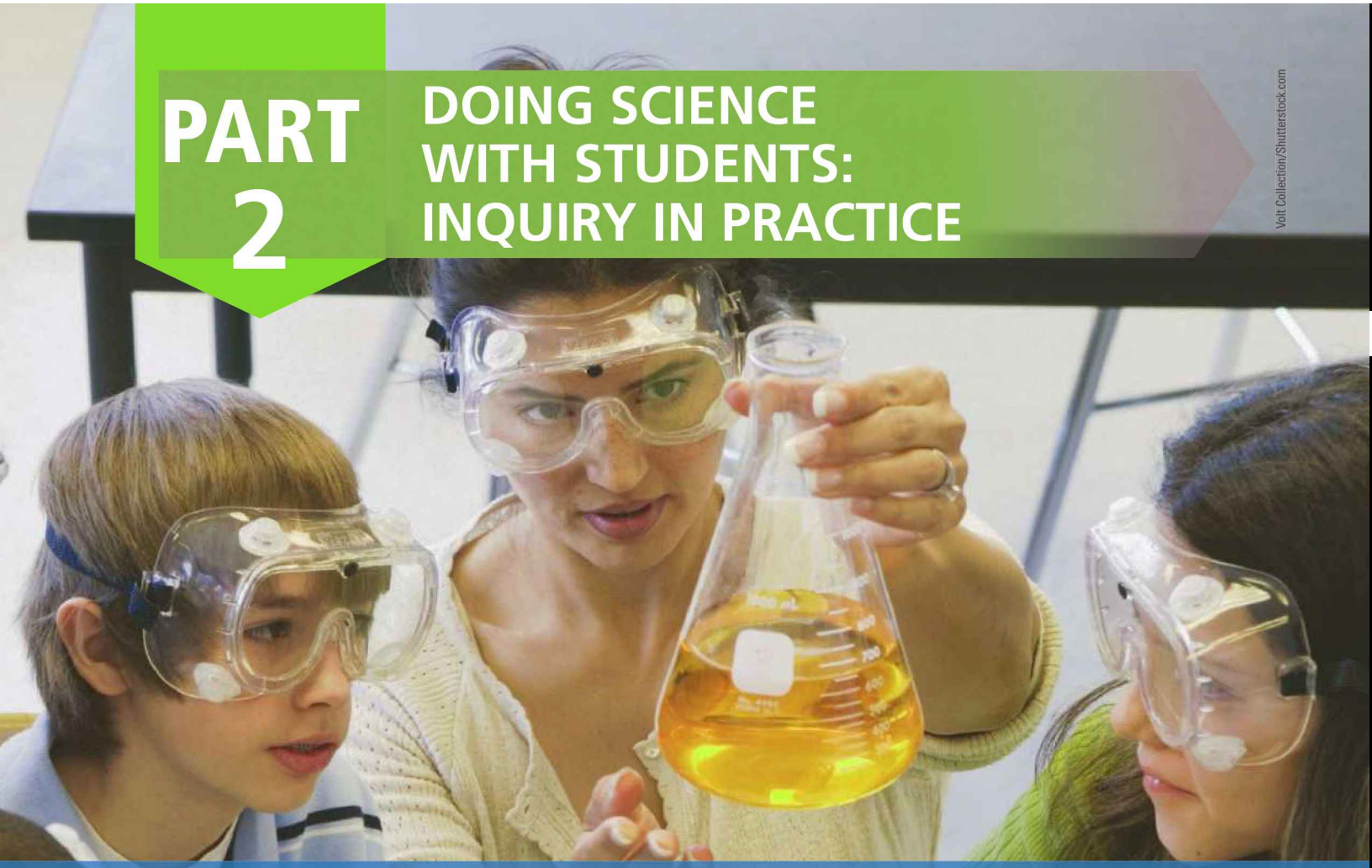
PART 2 DOING SCIENCE WITH STUDENTS: INQUIRY IN PRACTICE



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CHAPTER 2
Teachers and Students as Science Learners

Next Generation Science Standards

- **Crosscutting Concepts:** 2, 3, 5, 6
- **Disciplinary Core Ideas:** 2-PS1-1, 2-PS1-4, MS-PS1-4
- **Science and Engineering Practices:** 1, 2, 3, 4, 5, 6, 7, 8

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 2-1 Discuss how to help students make meaning of concepts for themselves.
- 2-2 Recognize the ways to facilitate student learning.
- 2-3 Examine how the science teacher becomes a mediator of students' ideas.
- 2-4 Examine the role of alternative conceptions in the social context of teaching science.
- 2-5 Explore concept maps as a way to help students make meaning.
- 2-6 Discuss the importance of students' own ideas.

Reflection

To Think About:

- As a child, did you ever invent your own theories for why things happened—theories that were useful at the time but did not match what the rest of the world was thinking?
- Why do you think "hands-on science" is not sufficient to help students learn science concepts?
- What do you think of when you hear the term "mediator"? How might it apply to science teaching?

2-1 Making Meaning: A Personal Story

Chapter 1 invited you to begin discovering your scientific self. As you did, you probably revisited your childhood wonderings and wanderings. One new teacher, who grew up in an urban area, remembered wondering why it was always cool in the summer in the basement of the apartment building where she and her family lived.

Children have many questions like that, but too often schools do not make room for these questions, and the children grow up, as this teacher did, with their questions unanswered. This happens because teachers, no doubt meaning well, approach science teaching and learning from their own perspective only. They ask themselves, in effect, "What do I have to *transmit* or *deliver* to my students?" As you will see in this chapter, science teaching is much more about the exchanges that occur between teachers and students as they explore science together.

When I was a little girl, growing up in an inner-city apartment building with six floors and twenty apartments on each floor, I always wondered how the mail made its way to the little mailbox that belonged to my family. It was on the second row of all the boxes—the fourth one in from the left. When I was six years old, I was allowed to use the small key to open the mailbox assigned to my family and "take out the mail." This was my daily job after school. I had my own personal theory about mail delivery. I imagined that, when the envelope was dropped in the public mailbox on the corner, a tube carried it through underground chutes to its destination in my little mailbox. Even at the age of six, however, I was troubled by not being able to explain how the letter knew how to get to my mailbox.

One day, when walking with my mother, I bent down to look under the mailbox on the corner. "What are you looking for?" she asked. "I was wondering where the tubes were," I responded. "What tubes?" she asked, and I then proceeded to share my theory. Nodding, she said that she could not explain right then how the mail got to the mailbox but she would arrange a way for me to find out.

Shortly thereafter, I was home ill from school, in the care of my grandmother. My mother called from work and asked Grandma to take me down to the

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mailboxes at the precise time that Artie, our mailman, would arrive. She bundled me up and I was able to witness the mailman, with his special key, open the portal to all of the mailboxes in the building. One box at a time, he inserted the mail in the various boxes.

He allowed me to help him, thrilled with my curiosity about how mail "knows" where to go. He also invited me and my family to the local post office for a view of how the postal workers sort the mail for the various neighborhood routes.

This experience demonstrates, for me, what it means to directly observe a phenomenon as I set about understanding more of my external world. It would have been easy for my mother to say, "No, Janice, mail does not travel through tubes in the ground." Instead, she honored my theory, found it quite interesting, and arranged for me to have the direct experience that would challenge my beliefs about underground tubes and mail delivery. By observing how the mailman opened all the mailboxes simultaneously with his large master key, I saw people as an intricate part of the mail delivery process. I began to expand my thinking! It no longer mattered that my idea was incorrect—because the authentic explanation made so much sense.

While you rediscover your own scientific self, you will also notice the ways in which your students express *their* scientific selves when you engage them in meaningful science activities. As we mentioned earlier, students construct meanings from science experiences on the basis of who they are, where they have been, and their own prior understandings. In this chapter, you will see how you can act as a mediator and facilitator in this process, helping your students to construct their own meanings by listening to their ideas and learning about how they think.

Much of our work will center on science stories—narrative accounts of actual experiences that teachers, including myself, have had while doing science with students. After each science story, look for ***The Teaching Ideas behind This Story*** and ***The Science Ideas behind This Story***. These sections will help you to think about the teaching strategies and the core science concepts illustrated by the story. The **disciplinary core ideas (DCIs)** and the **science and engineering practices (SEPs)** as well as the **crosscutting concepts (CCs)** from the Next Generation Science Standards will be indicated where applicable in the ***Connections to the Next Generation Science Standards*** section. Look for their inclusion in the discussion of the science stories. The ***Exploring Further*** section will help you to think about how this experience can happen in ***your*** classroom. As you will see, the science stories reflect the three main branches of school science:

disciplinary core ideas (DCIs)
Science concepts addressing four domains: life science; physical science; earth and space science; and engineering, technology, and applications of science. These concepts are represented by learning progressions as students' ideas mature over time.

science and engineering practices (SEPs)
The use of a particular set of practices for engaging in scientific inquiry and engineering design, providing insights into how scientific knowledge develops and gaining an understanding of the work of engineers.

crosscutting concepts (CCs)
A way of linking and thinking about the disciplinary core ideas in science. These concepts help students develop a coherent and scientifically based view of the world.

- In ***life science***, students and teachers explore characteristics of living things and their interactions with the nonliving environment. The current interest in "green science," which stresses the impact of human development on natural environments, falls into this category.
- In ***physical science***, students and teachers look at properties of objects and materials, forms of energy, and the motion of objects.
- In ***earth and space science***, students and teachers investigate properties of earth materials, objects in the sky, and changes in the earth and sky.
- Look for examples of *engineering design* and chances for students to apply their knowledge of science in the design and construction of an experiment or an object.

At times, you may engage all the students in a similar experience at the same time, or you may involve different groups in different activities that are centered on a similar theme. Sometimes you may show the students a natural event by way of a demonstration. That is what happens in the following science story.

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SCIENCE STORY

The Bottle and the Balloon

I am visiting Ms. Hudson's third-grade class in a suburb of a major northeastern city. The twenty-four children come from many cultures—European American, Latino, African American, and Asian American—and a wide range of socioeconomic classes. I'm standing up front with the simple apparatus I've brought for this lesson.

The children watch as I place a deflated red balloon over an apparently empty vinegar bottle. It hangs limply to the side. I hold the bottle up to the class and ask, "What do you think is in this bottle?"

The children respond, "Air!"

I put this thick glass bottle into a pot of just-boiled water, holding the top to keep it upright. "Let's watch what happens here," I say. Slowly, the deflated balloon fills with air, until it stands erect at the top of the bottle.

The children are delighted. With only a little prodding from me, they carefully explain what they observe, and we record it: When we put the bottle in the hot water, the balloon filled up with air. "Where do you think the air has come from?" I ask. "What are some of your ideas?"

> ***My thinking:*** *At this point I am wondering if the children will grasp that making the bottle hot will heat the air inside the bottle and that the warm air expands and causes the balloon to inflate. I do not expect the children to have that level of knowledge, but I do hope they will make some connection between the heated air and the balloon's inflating. Instead, the children give me some creative but quite different explanations.*

"The steam from the boiling water went through the glass and inflated the balloon," a boy named Mike offers.

"That is an interesting idea," I answer. "Have you ever seen steam go through glass before?" After thinking for a moment, he does not remember having seen steam go through glass.

A girl named Jamila agrees with Mike's focus on steam but has a different idea about the mechanism: "The steam seeped into the balloon because the seal between the balloon and the bottle was not airtight." I respond, "That sounds as if you have really been thinking about this. Do you think that my placing the bottle in the hot water helped the steam to seep in?" Jamila says, "Yes, it helped steam get in."

It's clear to me now that several students think that steam seeped into the balloon. I continue to question them about their thinking: "Do you think that if we made the seal between the bottle and balloon tighter, we could prevent the steam from seeping in?" The students believe this is true, so I ask them how we should do it. They decide to take several bottles and balloons and securely tape each new balloon onto its bottle before placing it in the pot of hot water. We try four different setups with bottles of different sizes and shapes as well as balloons of different sizes and shapes. In each case, the balloon still inflates.

Though the results contradict their own ideas, the children enjoy watching the balloons inflate. Each time I repeat the experience, I invite the students (especially those who most firmly believe that the source of the air is *outside* the bottle) to stay close and observe. Jamila looks hard for steam seeping into the bottle. Mike holds the balloon tightly around the neck of the bottle to make sure it is airtight.

After the four additional tries, I ask the students what they are thinking now. At this point, they have mostly decided that the air inflating the balloon must be air that was already inside the bottle. We make connections between this experiment and hot air balloons as well as to the places where we find the hottest room in our houses during the summer. Some students are coming, in their own way, to the science idea that I was hoping they would grasp, namely, that warming the air changes the way the air behaves.

In these experiments, as the students have noticed, the balloon always fills gently and partially with air; it does not inflate completely. I ask them why they think the balloon did not blow up more than it did. Some students remark that it could fill up only with the air that was already in the bottle when we started. "Hooray!" I think. They really "get" it.

Finally, to help them build on their understanding, I ask myself what other demonstration I can do to show that there is air in the bottle. We proceed to take the balloon off the bottle and invert the "empty"

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bottle in a basin of water. The water does not rise in the bottle. Some students say that it must be the air in the bottle that keeps the water from entering.

As I am ready to leave Ms. Hudson's class, she asks the students to take laptop computers from the classroom laptop cart and visit a website about hot air balloons. With the links and pictures on this website, Ms. Hudson asks the students to do the following exercise:

> *Pretend you are going to take a hot air balloon ride. Write a letter to a friend about your upcoming adventure and be sure to include answers to the following questions: Where is the closest balloon site to our school? What is the science idea behind the way balloons operate? When did people start using hot air balloons? What is the source of heat energy for these balloons? In your opinion, how safe are they?*

The Teaching Ideas behind This Story

- When students simply repeat answers they have heard, we cannot be sure that there is any deep meaning in this knowledge. The students in Ms. Hudson's class all agreed that the bottle contained air. Nevertheless, I could tell that many were not comfortable with this idea. For some, it was just a rote answer, something they had been told was true but hadn't fully incorporated into their own thinking. *Grasping terminology is not the same as understanding the concept or being able to apply it in a real-life context* (Brooks & Brooks, 2001; Yager, 1991).
- When I asked Mike if he had seen steam go through glass, I was not making fun of his idea. Instead, I was trying to draw out his prior experiences that might have contributed to it.
- Notice how I treated the children's "wrong" ideas with respect, inviting them to test whether those ideas were true. This is a vital technique that we will discuss further in the next section.
- Although the experiment began as a demonstration, it quickly became a participatory event as the students suggested their own variations.
- Notice how Ms. Hudson used readily available networked computers to extend the lesson with a related language arts exercise based on hot air balloons. This connection to language arts is both natural and useful, and it encourages the students to express their understanding of the science idea in their own words.
- When Ms. Hudson asked students to do research on hot air balloons, she was also applying standards from the *National Educational Technology Standards for Students*, or NETS-S (International Society for Technology in Education, 2007), that state that students apply digital tools to gather, evaluate, and use information.

The Science Ideas behind This Story

- Although air is all around us and seeps into everything, it is a difficult concept for young students to understand. They can blow air onto their hands, feel the force of a breeze—but, still, it is a tricky concept. Air that is warmed expands. Its particles move faster and become farther apart. If this air has room—that is, if the walls of the container are not too rigid—the warmed air particles continue to move farther apart. Because its particles are farther apart, this warmed air is now less dense. In the experiment in Ms. Hudson's class, the colder air above—denser, with its particles closer together—dropped down, pushing the warm air upward.
- The method by which heat energy travels in liquids and gases is called *convection*. You can read more about convection in Chapter 10. Ms. Hudson or I could have introduced this term and asked the students to memorize the definition. But even after learning the term, they might have been unable to relate it to the balloon and the bottle.

Connections to the Next Generation Science Standards

- **NGSS DCI: 2-PS-1.A: Structure and Properties of Matter:** Different kinds of matter exist and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties. Heating or cooling a substance may cause changes that can be observed.

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- **NGSS SEPs:** Ms. Hudson's students were *planning and carrying out an investigation; engaging in argument from evidence;* and *obtaining, evaluating, and communicating information.*
- **NGSS CCs:** Ms. Hudson's students examined the phenomena of *cause and effect*, trying to find an explanation for the inflating of the balloon!

Exploring Further

If you were teaching this lesson, using the bottles and the balloons, you may want to understand answers to the following questions:

- How is *convection* of heat energy in the balloon experiment different from the *conduction* of heat that occurs when you touch a hot stove?
- What stories do you know that involve hot air balloons? What principle is behind the operation of these balloons?
- How might you help young students discover that air has weight and takes up space?

2-1a Helping Students to Make Meaning

Let's reflect further on what happened in Ms. Hudson's class when I helped the students experiment with bottles and balloons. As we noted in Chapter 1, the view that learning is an active process of knowledge construction is part of a family of theories called *constructivism*. Contemporary constructivism reflects what we now know about how people learn (Donovan & Bransford, 2005). In order to understand a concept, individuals *must* be engaged in the active process of making sense of their experiences. Simply "knowing" something does not constitute understanding. Instead, we gradually come to understand ideas as we turn them over in our minds and reflect on our experiences.

For students, true understanding means that they can discuss concepts freely and apply them to other areas of thinking. Students' prior knowledge is central to building this kind of understanding, and the process of reflecting on their own thinking helps them to make meaning of the "science ideas."

2-1a Prior Knowledge

The philosopher John Dewey said that concepts should be viewed as "known points of reference by which to get our bearings when we are plunged into the strange unknown" (1933, p. 153). That is, concepts don't just sit there in our minds; they help us interpret and deal with new situations. In turn, these new experiences help us refine our concepts. I like to think of our concepts as old friends—ideas we come to know as we grow and that we refine and revisit as we add new understandings to our repertoire. Our repertoire of such understandings is our **prior knowledge**. When I asked Mike in Ms. Hudson's class if he had experiences with steam before, I was trying to access his prior knowledge.

prior knowledge
What an individual has learned from all his or her previous experiences. This plays a crucial role in determining how the person integrates a new concept.

To a casual observer, it may not seem that the students in Ms. Hudson's class knew very much about the matter at hand. Nevertheless, the prior knowledge they possessed was extremely important. They knew that boiling water gives off steam, for example, and they certainly understood some of the characteristics of steam.

As I conducted my experiments, I was really interested to learn that several students thought that the balloon inflated because of the steam from the just-boiled water. If I had merely told them something different, they might have

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nodded at me but failed to derive any real meaning from what I said. Instead, because my interest in their thinking was genuine, the students knew that I valued their ideas and respected their prior knowledge. This leads us to our next crucial point.

2-1a Valuing the Students' Thinking

Valuing the students' ideas is a way of communicating to them that their thinking is important to the class community. When students' ideas are genuinely valued, they begin to see themselves as *knowers*. Only as knowers can they construct new meanings by building on their prior beliefs and ideas.

This is a vital principle to grasp. Creating an atmosphere in which there is a sense of trust makes it possible to help the students reflect on their new experiences and use those reflections to modify their prior knowledge. Without such trust, the students are not likely to do much serious thinking about the science experiences in which you engage them. They may memorize a "fact" or two, but their underlying ideas may remain unaffected.

When you inquire about students' thinking, you need to be ready for many types of responses. *All* of their responses have value because they provide insight into the students' thinking. If you tell the students your thinking first, they will never feel comfortable sharing their own ideas. The students will immediately think the way you think, or at least they will say they do. This is called playing the "teacher game," and even young children are good at that.

If students have difficulty reaching a "correct" scientific understanding, that is okay. Listen to their ideas and reflect on them. Ask the students questions that help you understand the nature of their prior knowledge. Encourage them to:

- Write about and draw what they have observed.
- Create stories and poems about their science activities.
- Plan other similar experiments to test their personal ideas.

Such experiences encourage them to come up with their own ideas and offer those ideas in the discourse of the classroom.

Science activities and experiments need to provide students with the freedom to say exactly what they think—even if that is the *freedom to be wrong*. In the rest of this book, you will find many examples of this teaching strategy. You will also learn the many ways in which teachers help students to correct their misconceptions and reflect on the accurate ideas behind the science experience. This was demonstrated in Ms. Hudson's class and will be reflected in Mr. Wilson's behavior later in this chapter.

2-2 Facilitating Students' Learning

> *In my entire life as a student, I remember only twice being given the opportunity to come up with my own ideas, a fact I consider typical and terrible.*
> —Eleanor Duckworth

mediator
A teaching role in which the teacher helps students to learn by reflecting their own ideas back to them and guiding them in sorting out the inconsistencies.

If our interest is in helping students construct meaning, then we have to teach in ways that facilitate that process. The challenge is to help students delve deeply into their thoughts and expand their own thinking about an idea. Our role therefore becomes that of a **mediator**. In everyday terms, a mediator serves as a go-between of some sort, often by helping people resolve their differences

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by bridging the gaps between their points of view. A teacher who is a mediator helps students to bridge the gap between their initial understanding and the deeper knowledge they can build as a result of the lesson. The teacher can do this in a variety of ways, but the process usually begins by exposing students to new experiences and helping them to probe their own thinking. (In terms of the science learning cycle described earlier, the teacher's mediation takes place during the explanation and elaboration phases.)

In the bottle-and-balloon lesson, I was helping the students probe their thinking by inviting them to try the experiment again in different ways. I facilitated that process by providing additional materials and becoming the mediator of their ideas. It wasn't easy. The students who believed that the air inflating the balloon came from outside the bottle had a hard time realizing that anything was already in the bottle when we started. Although they said "air" when asked what was in the bottle, they were merely being correct, not truly understanding the concept.

Hence, I encouraged them to test their own theories. By "theories" in this context I mean their proposed explanations for a natural event. In science, as we noted earlier in the book, the term *theory* means a belief about a science idea that has a lot of observable evidence to support it. By *students' theories* we refer to their beliefs based on their own understandings at their particular level of cognitive development. These may not be full-fledged theories in the scientific sense, but they can lead to genuine theory building as students construct further meaning. Students discuss ideas with one another as well as with you, the teacher. When groups of students become involved, the conversation often involves three or four people or more. This is what is meant by the *social construction of meaning*, a phrase that is frequently used to emphasize the importance of social context in learning. In a genuine class or group discussion, students listen to and respond to each other as well as the teacher. With this style of communication, students can flesh out their ideas and make meaning from them. In the end, this type of science teaching yields a deeper, more important, and more valid understanding of science ideas.

2-1a Alternative Conceptions

alternative conception
An idea that is not scientifically accurate but represents a step toward full understanding of a concept.

As the bottle-and-balloon story demonstrates, different students construct meaning in different ways, and sometimes their ideas amount to **alternative conceptions**—ideas that are not scientifically accurate but represent a step toward full understanding of a concept. Some people refer to inaccurate ideas as misconceptions, but the term *alternative conception* helps us realize that these ideas serve a purpose. Alternative conceptions are like stops on a train route. They are places the students pass through on their journey to fuller understanding. Obviously, teachers need a thorough grasp of the science concepts behind a given topic to know when the students' own ideas represent steps in the path toward fuller understanding. As a teacher, you achieve that grasp by exploring science experiences and science concepts one topic at a time—and by locating your inner scientist. (Do not worry; it is doable and very rewarding. Chapter 10 contains some useful scientific information to jump-start your science content knowledge.)

When students reveal alternative conceptions, teachers need to evaluate those ideas and take action (Photo 2.1). This "action" is what your role as mediator is all about. Valuing the students' ideas does not mean you must let them go unchallenged. Instead, you invite your students to examine their conceptions from multiple perspectives—making connections between the experience and something else in their memory, or trying the experiment again in a different way. Thus, I asked Mike if he had ever seen steam go through a bottle before. I asked the students, too, if they thought making the seal tighter would prevent

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Tetra Images/Alamy Stock Photo

PHOTO 2.1 This teacher and her students engage in an in-depth conversation about a project. By respecting and encouraging the students' own ideas, the teacher helps them reach a deeper understanding.

the steam from seeping into the balloon, and I guided them to explore that possibility. Through such means, we help them refine their ideas so their thinking matches their own enlarged experience.

2-1a Scaffolding

scaffolding
Providing temporary support or guidance to a learner who needs help to reach understanding of a concept or process. The scaffold can take such forms as key questions, important facts, a structure to frame the problem, and modeling or demonstration by the teacher.

When teachers facilitate student understanding, they help students by **scaffolding** their learning. In daily use, *scaffold* refers to a temporary platform or ledge that physically supports workers while they complete jobs above the ground—for instance, installing windows on the fifth floor of an office building. In education, the term *scaffolding* also refers to a temporary "ledge," but in this case the platform is an intellectual place—a step on the road to understanding the core concept. Just like the worker who could not complete his or her job without the scaffold, learners need scaffolding support by teachers to develop their science understanding.

The temporary scaffolding that teachers provide may include guidance during an investigation or key questions for students to think about. Sometimes the scaffolding is additional information that helps students move to the next step. In a later chapter, you will see a teacher scaffolding student learning by providing a "fact sheet" about the effects of salt water on living things. In Ms. Hudson's class, the scaffolding included the questions I asked and the experiment with the balloons taped to the necks of the bottles. Look for the scaffolding that Mr. Wilson uses in the next science story.

2-3 Teacher as Mediator

Helping students to think about natural phenomena often requires a conversation where the teacher is guiding the student to consider another direction or another way of thinking. Such is the case in the following story.

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SCIENCE STORY

Icicles

It is an icy-cold winter morning in the Northeast. It snowed two days ago, and the temperature has plummeted to well below the freezing point of water. Ice and snow cover everything.

On his way to school in this urban community, Mr. Wilson notices icicles hanging from the edges of roof lines. The icicles glisten in the sun. They are of varying lengths and thicknesses. He reaches up and breaks off some extra-long ones and brings them to his third-grade classroom, where he stores them temporarily on a ledge outside the window.

After the morning business, Mr. Wilson retrieves the icicles and shows them to the children. "Where do you think I found these?" he asks. The children call out all the places where they saw icicles this morning. Some of them noticed icicles hanging from tree branches; others saw icicles on roofs and awnings. Still others didn't seem to notice any icicles at all. As a group, the children are excited that Mr. Wilson has brought some icicles to class. He describes how he reached up to a low roof and gently pulled them off, trying not to break them.

"What are all the things you notice about these icicles?" Mr. Wilson asks.

The children respond in various ways: "They're long." "They're cold." "They're cloudy." "They're hard." "They're pointy." "They will start dripping when they melt." "You can hurt someone if you stick it into them!"

"Let's explore these things before they melt," says Mr. Wilson. "What are your questions? What do you want to find out about these icicles?"

Some children are interested in knowing how long it will take for them to melt. Others suggest different questions:

"Will they weigh the same when they melt as they do now?"

"When they melt, will they be the same color?"

"Can we make them back into an icicle after we melt them?"

"Do they taste good?"

Mr. Wilson's thinking: *Notice that Mr. Wilson has asked the students to think about what they want to know about the icicles. He knows that what is really important is the students' questions—the ones they cannot answer yet, the ones that compel them to search for answers.*

Mr. Wilson engages the children in a discussion of their questions. They talk about why it may not be a good idea to taste the icicles. (Some children think they may be dirty.) Most of the children want to make the icicles melt. Some children want to place the icicles on the classroom heater. Some want to light a candle (Mr. Wilson would do that for them) and hold the icicle over it. Some children want to place the icicles on the window ledge, where the sun is streaming in.

At this point, Mr. Wilson temporarily returns the icicles to the outside ledge. He asks the children to divide up into their usual science groups. Each group will get an icicle to work with, he says, and each group should decide in advance what to do with it before it melts. As a suggestion, Mr. Wilson repeats one of the ideas the students themselves proposed: "Let's do find out," he says, "if our icicles weigh the same when they melt."

As the children are deciding on their procedures, Mr. Wilson visits each group and coaches them. He points things out to them and asks them to explain what they have come up with. He prods them, leading them with his questions, coaxing and coaching their planning. "What should we do to find out if the icicles weigh the same after they melt as they do now?" he asks various groups.

"Weigh them, before and after," the children figure out.

Mr. Wilson's thinking: *Although this is an impromptu lesson, Mr. Wilson has an objective in mind. He's hoping the students will begin to learn what melting really is. The question about an icicle's weight before and after melting was an important one, so he stimulates their attention to it. He also guides them in framing their*

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investigations so they will be able to explore the changes that occur when the icicle melts. He points things out and inquires about their plans. He is somewhat like a tour guide or a coach. Unlike a tour guide, however, he does not explain the details of all the sights. Instead, he listens to the students' impressions and asks for whatever meanings they may construct.

It turns out that one group cannot decide what to do. Mr. Wilson asks them what they have thought about so far. One student explains that "Jamie wants to make something that will keep the icicle from melting," while the rest of them (three other children) want to time how long it will take to melt.

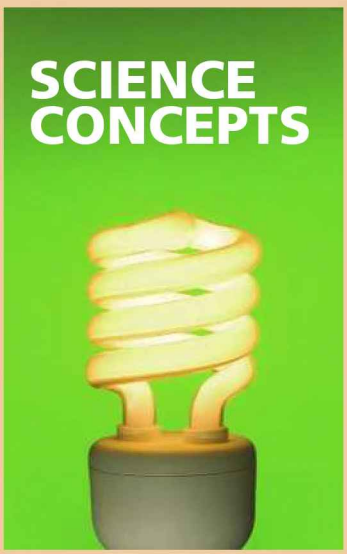
Mr. Wilson thinks about this dilemma and asks Jamie what question she has in mind. Her question is, "How long can I keep the icicle cold?" She wants to wrap the icicle up with materials from the classroom and put it in a shoebox. "Why are you interested in doing that?" asks Mr. Wilson. Jamie replies, "I want to see if I can keep it cold long enough to take it home."

"Okay," Mr. Wilson says, "why doesn't Jamie do that with one icicle? The rest of you can take another icicle and work on your plan to melt it."

Mr. Wilson's thinking: *Although his main focus in this lesson is on melting, Mr. Wilson doesn't force all the children to work on that. He knows that Jamie is becoming invested in exploring her own question, so he allows this to happen.*

When the groups have decided on their questions and procedures, Mr. Wilson takes out the scales—the double-pan balances commonly used for measuring mass in elementary grades. He distributes an icicle to each group, giving an extra one to Jamie. But before the students begin to weigh the icicles, he asks them, "How will you collect the water while your icicle is melting?" (Some of the icicles are already dripping.) The children have to consider the problem. He invites them over to the science supply table and asks for suggestions. They look at the plastic cups, aluminum foil pie pans, shoeboxes, and assorted plastic containers. Someone suggests that they allow the icicle to melt in an aluminum pie pan. Mr. Wilson encourages this idea since the pie pans are flat and can accommodate the icicles without tipping over.

Mass and Weight



In elementary and middle school science, students learn some basic ideas about matter. Matter can be defined as anything that has weight or mass and takes up space (as opposed to energy, for example, which has neither of those qualities).

Mass refers directly to how much matter is in an object. Often, the term *weight* is used interchangeably with *mass*, but in scientific usage, the two are different. *Weight* means the gravitational pull that the earth has on an object.

Since the gravitational pull of the earth is relatively constant, mass and weight are essentially the same on earth. But if you weigh an object on earth and then take it to the moon, it will weigh only about one-sixth as much because the moon's gravitational pull is about one-sixth as strong as the earth's. The object's mass, on the other hand, will be the same in both places.

Even on earth, the nearer a body is to the center of the earth, the greater the downward pull of gravity on the body and the more the body weighs. The farther a body is from the center of the earth, the less the body weighs.

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> *All of us learn through our experiments. Do we give ourselves the freedom to experiment, the freedom to be wrong, the freedom to be right … for a little while … until we turn out to be wrong again?*
> —Jacqueline Grennon Brooks and Martin Brooks

Now he asks the children to weigh their icicles. As their standard masses, the children use teddy bear counters: thick plastic figures, about 5 centimeters long, shaped like teddy bears. (Standard unit masses may be in gram units or in any other convenient units—for example, paper clips or pennies.)

In their small groups, the children take turns with the double-pan balance. Some children weigh the icicle and the pan together. Others weigh just the icicle. Mr. Wilson observes each group and does not give specific instructions. The children realize that the icicles have to be weighed quickly before they melt.

Mr. Wilson's thinking: *Mr. Wilson does not want to direct the students in how to weigh their icicles. Instead, he gives them the freedom to experiment—the freedom to be wrong and then to explore further until they are right. He watches, he suggests, he leads a bit, and then he lets go—until (as we will see) he needs to intervene. He is mediating their experience.*

After the weighing, the children proceed with their different plans for melting their icicles. One group, which has weighed the icicle in the pan, places the pan on the sunny windowsill and checks it every few minutes until the icicle melts. Then the group members weigh the melted icicle in the pan and compare the two measurements they have made:

icicle + pan = 20 teddy bears

melted icicle + pan = 20 teddy bears

Other groups follow different methods of melting and come up with similar results in the weight test.

Predictably, however, the groups that have weighed an icicle by itself, outside the pie pan, run into trouble. For instance, one of these groups proceeds to melt the icicle in the pan on the heater and then weighs the resulting water in the pan. This group concludes that the melted icicle weighs more than the solid icicle. Now Mr. Wilson intervenes. "What about the pie pan that you have the water in?" he asks. "Doesn't it weigh something?"

The children look at him. He explains, "You weighed your icicle on the balance scale all by itself, but you weighed the water in the pan. If you weighed the icicle all by itself, then you would have to weigh the water all by itself."

Thinking about this, the children come up with a new plan. They ask Mr. Wilson if they can try the experiment again with another icicle. "Yes," he says, and gives them a new one to work with. He has been keeping extra icicles outside the classroom window.

Mr. Wilson's thinking: *Mr. Wilson intervenes when he realizes that the children have come up with an alternative conception, an idea that has been constructed from their experience but is not scientifically accurate. He sets them on a path that will help them build a more accurate idea.*

It is interesting, though, that Mr. Wilson does not tell them to find the mass of the pie pan by itself and then subtract that from the total mass of the pie pan and water. The children have not thought of that option, and Mr. Wilson decides to allow them to redo their experiment rather than impose his procedure on them. This is an important decision: finding the right balance between guiding the procedure and allowing students to experiment for themselves. Here we see another facet of the teacher as mediator.

The group that is redoing the experiment begins by weighing the icicle *in* the pan this time. They decide to let the new icicle melt in the pan on a table in the back of the room. This icicle takes longer to melt, so they weigh the resulting water after lunch. This is their result:

icicle + pan = 15 teddy bears

melted icicle + pan = 15 teddy bears

Once all the groups are finished, Mr. Wilson again engages the entire class in discussion. The students all agree now that you have to weigh the icicle in the pan at the beginning, and then you have to weigh the

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melted icicle in the pan at the end. They also agree that an icicle's weight does not change when it melts, though most of them are surprised by this conclusion.

"Well, what did you think would happen?" Mr. Wilson asks. The children say that the melted icicle looked so little compared to the original icicle that they thought it would weigh less.

"What other melting experiments can we do?" Mr. Wilson wonders aloud. The children suggest using ice cubes to see if the same thing will happen. Mr. Wilson promises to bring ice cubes to class the next day. Meanwhile, Jamie has wrapped her icicle tightly in aluminum foil and paper towels before placing it in a plastic bag and putting it in a shoebox to take home.

The Next Day: From Icicles to Ice Cubes

The following morning, the children in Mr. Wilson's class come to school ready to see if a pan of ice cubes will weigh the same before and after melting. This experiment was the children's own idea, and it generates curiosity and profound interest.

Before addressing the ice cubes activity, however, Mr. Wilson gives Jamie a chance to present her experiment to the class. She explained to the class that her icicle in the shoebox did last, but it became a lot smaller. When she got home, she put it in the freezer.

Now Mr. Wilson brings out three trays of ice cubes from the school refrigerator. Weighing the tray of ice cubes before and after melting will be a repeated experience, another visit to the concept of masses remaining the same when the state of matter changes. It is an example of assessing how well the children can *apply a concept* they learned the day before. Once again, Mr. Wilson is engaging them in solving a problem, setting up an experiment, testing their own ideas, and drawing some conclusions.

But the students now are also interested in Jamie's type of experiment. They want to know if they can try different techniques to preserve the ice cubes. "Sure," replies Mr. Wilson. One ice cube tray can be used for melting, and the others can supply the cubes for the new experiments. Mr. Wilson sees that the class's further explorations can lead to ideas about the concept of insulation and the losing and gaining of heat energy. In this way, one student's question has become an entire class's experiment.

The Teaching Ideas behind This Story

- The way Mr. Wilson used the icy weather to engage the students in a science activity reflects an important connection between the environment outside the classroom and the activity within it. Making this link is a very important part of doing science with students. We will return to this idea in Chapter 4.
- Clearly, Mr. Wilson was engaging the children in a constructivist learning activity. Notice how he listened to their ideas about icicles, weighing, and melting, and then encouraged them to try out their notions. This method helps students recognize what they already know and build on it. For example, the students knew that the icicles would melt if kept indoors. They had their own ideas about places where the melting might happen quickly—the heater in the classroom and the sunny window ledge. Their prior knowledge also helped them choose an appropriate container in which to place each icicle before they melted it. Because Mr. Wilson acknowledged them as knowers, they could proceed to experiment with confidence.
- Nevertheless, Mr. Wilson did not ignore what they were doing or let them experiment entirely without help. Instead, he *mediated* their experience by giving them suggestions and guiding their activities.
- There are those who will think that Mr. Wilson should have told the children at the beginning that they needed to weigh the icicles in some kind of receptacle. Such an instruction may be time efficient, but it does not promote the development of the children's own ideas. He wanted the children to explore on their own (Photo 2.2) so they could learn the best way to measure their icicles. For that reason, he created an atmosphere in which the children had the opportunity and *intellectual freedom* to investigate their notions. He also gave them the tacit message that it is okay to be "wrong."
- When one team of students decided that the water weighed more than the original icicle, Mr. Wilson knew that this was an alternative conception that could become a stopping-off place en route to deeper

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Jim West/PhotoEdit

PHOTO 2.2 Examining mud samples from a river, these students explore their own questions and discuss their ideas.

meaning. At this point he stepped in to provide some crucial information: He pointed out that if the students had weighed the icicle without the pan, they would have to weigh the water the same way. Good teachers supply enough information to show students the right path but not so much as to discourage students from thinking on their own.

- Mr. Wilson did not know in advance exactly where the icicle experience would lead. He did not impose a rigid procedure. He was intending that the students learn something about melting. But Jamie, the student who kept the icicle cold, would also learn something about insulation. He did make sure that each group explored the question of weight before and after melting—a question that the students themselves had raised in the beginning when he prompted them for ideas.
- Do you see how the approach to learning Mr. Wilson took in his class parallels the scientific process itself? In professional science, one experiment often leads to another experiment because somebody in the research team has a new but related question. In the same way, Mr. Wilson's students, stimulated in part by Jamie, follow their own questioning from one exploration to another.

The Science Ideas behind This Story

- The activity in this story addresses what happens when matter *changes state*, in this case from a solid to a liquid. The students observe that when a certain amount of matter changes state, its mass does not change. Changes in state are associated with different amounts of energy, but the amount of mass remains constant before and after the change of state. Each group of children added heat energy to its icicle so that it would melt. The icicle absorbed the heat energy. That caused its particles to move faster and spread farther apart, turning the solid into a liquid. But the additional energy did not affect the mass.
- The states of matter are a foundational property in physical science. They help students to understand the world around them, and they become prior knowledge on which to build more complex concepts, such as atomic structure.

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- Icicles form when snow or ice collects on an elevated surface and the air is around the freezing point of water, 32 degrees Fahrenheit or 0 degrees Celsius. If snow or ice melts in a sunny area and drips down to a shaded area, it can refreeze in a column as an icicle.
- This activity helped students understand that when you are weighing the same object in different forms, the method you use is very important. There is a key general principle here. In a science experiment we always ask, "What are we keeping the same? What are we changing?" Scientists call these **constants** and **variables**, respectively. The students were changing the state of matter; therefore, to make this a fair test of the effect on weight, the conditions under which the two states were weighed had to be the same. A **fair test** in science requires that we keep all of the experimental conditions the same (constant) except the one that we are testing for (the variable).

Connections to the Next Generation Science Standards

- **NGSS DCI: 2-PS1-4: Chemical Reactions:** Heating or cooling a substance may cause changes that can be observed. Sometimes these changes are reversible; sometimes they are not.
- **NGSS SEPs**: Mr. Wilson's students *planned and carried out investigations*; *engaged in argument from evidence*; *constructed explanations*; and *obtained, evaluated, and communicated information*.
- **NGSS CCs:** Mr. Wilson's students examined *scale, proportion, and quantity* as a way to determine that the amount of matter they had at the beginning of their investigation was the amount of matter that remained at the end. Further the Crosscutting Concept of *energy and matter* asserts that *matter is conserved because atoms are conserved in physical and chemical processes*. Melting is a physical process.

Exploring Further

If you were teaching this lesson, having collected icicles from the outside, you may want to understand answers to the following questions:

- In what ways do you think the icicle activity stimulated the students' thinking processes?
- What prior experiences do you think the children were relying on to construct new meanings?
- What science ideas did the teacher need to know before engaging children in this activity?
- What connections could you make from this lesson to literature or social studies?
- How might you integrate technology into this activity?

2-4 The Social Context of Teaching and Learning Science: Alternative Conceptions

mass
The amount of matter that is in an object, typically measured in grams and kilograms.

constant
An experimental condition that remains the same throughout a scientific investigation.

John Dewey (1933) talked about concrete experiences as the ground and generator of the thinking process. Remarking that experience would lead to the understanding of ideas and the capacity to conceptualize, he argued for hands-on learning fifty years before it became a catchphrase. This movement from objects to ideas is what rooting science learning in concrete experience is all about. Some researchers have used the terms *situated cognition* or *situated learning* to refer to the notion that the situation or context of learning is critical and that real learning takes place only when it is situated in real-world activities (see Snowman & McCown, 2015).

> *I think and think for months and years. Ninety-nine times, the conclusion is false. The hundredth time I am right.*
> —Albert Einstein

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variable
The property or condition of a scientific investigation that will change when experimental conditions are changed.

fair test
An investigation in which all the experimental conditions remain the same (constant) except for the one being tested (the variable).

Unfortunately, many science teachers, unlike Mr. Wilson, offer students hands-on activities that are completely predetermined and predictable. The teacher knows beforehand exactly where the students should end up. There are obvious attractions to this method; certainly you do need specific learning goals for your students. But the problem with imposing strict procedures on students when they are doing science is that the teacher does not learn what the students really think or how they construct meaning. Without learning what they think, it is extremely difficult to help them change or develop their thinking. Often students will score well on standardized tests and yet be unable to change the experience-based interpretations of nature they acquired prior to instruction (Yager, 1991).

It is important to recognize that alternative conceptions cut across age, ability, gender, and cultural boundaries. In a national study that collected data from more than 2,100 students in grades 3–5 (Barman et al., 1999, 2000), more than 13 percent of the students decided that an organism was not an animal if it didn't have fur. More than 9 percent of the students in the same age group explained that something couldn't be an animal if it wasn't a pet. An award-winning video, *A Private Universe*, shows that even Harvard graduates hold fundamental misunderstandings about the solar system. These examples point up the importance of using teaching strategies that are designed to reveal alternative conceptions and provide the repeated experiences that help change them.

Let's consider the icicles story again. Most of the children, seeing the small puddle of water left when the icicle melted, thought that it must weigh less than the original icicle. This is because, unlike other liquids, water expands when it freezes, taking up more space, and conversely it shrinks when it melts.

The idea that the water would weigh less than the icicle was contradicted by their experience. Without this experience, they might have memorized the fact that water expands when it freezes without really knowing in practice what that meant. It is only by becoming aware of students' embedded ideas about the natural world that we can begin to change their alternative conceptions. By providing opportunities for them to express their own ideas, talking about those ideas, and guiding them through tests of those ideas, we can mediate their development of more sophisticated and more accurate concepts. This role will take on deeper meaning for you once you experience it in your own classroom.

Some Strategies to Help Change Persistent Alternative Conceptions

- Listen to the students' ideas.
- Honor their thinking by reflecting on their responses.
- Ask students to explain their thinking: "That's interesting—what makes you think that?"
- Alter experiments. For example, do the same experiment again with different materials.
- Ask students to devise a plan to demonstrate that their alternative conception works: "Could we plan an experiment to see if that works?"
- Remind students that people tend to hold on to ideas that they know are not accurate. Ask them, "Why do you think we do that?"
- Find multiple ways to express and apply the accurate big ideas.

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2-5 Concept Maps and Learning Science

Let's look at another illustration of how a teacher can facilitate students' learning by acting as a mediator. In this case, the students are in middle school, but the teacher again helps them to explore their own questions and develop their own ideas. In the last section of the story, you will see how the teacher deals with an alternative conception that arises.

SCIENCE STORY

The "Skin" of Water

The sixth-grade students in Ridgefield Middle School are mesmerized by the insects in the pond on the school grounds. On this warm winter day in the South, after many days of rain, the pond is quite full and the water very still. Ms. Parker has led the students outside to take some temperature readings of the pond so they can compare them with the measurements they took a week earlier. But before the students are settled around the pond, Henry shouts, "Wow, look at those two bugs!"

Skipping over the water's surface are two insects known as water striders. "Oooh, gross," says Lanie. "How do they walk on water?" Shondra asks. "Yeah," adds Shana, "how can they walk on water?" Ms. Parker opens the question to the class. "Well, what do you think, everyone?"

Ms. Parker's thinking: *Ms. Parker sees this question as a way to stimulate the students' thinking. For that reason, she doesn't leap to answer the question but instead asks the students for input.*

Some students say the insects must be very light to stay on top of the water. Another offers that the bugs seem to have pads for feet. "Their feet are far apart," says yet another student. As soon as the temperature readings are taken—the water temperature has gone down after the rain—Ms. Parker accompanies the students back to class and says they will explore Shondra's question in science period the next day.

> *Knowledge depends on questions, and the process of coming to "really know" something entails revisiting the essential concept in new settings, under new conditions, and with new parameters often enough to challenge one's own thinking.*
> —Jacqueline Grennon Brooks

The following day, I join Ms. Parker and her sixth graders as they perform a number of experiments with water. When I enter the room, the materials table is set up with cups of metal washers, basins, foil pie pans, index cards, and stacks of empty plastic cups. In Ms. Parker's class the students work in science teams and have assigned jobs. Each group has a materials manager, a director, a speaker, and a recorder, and these jobs are routinely rotated.

Ms. Parker asks the managers to collect a cup of washers, an empty cup, a basin, and a pouring cup filled with water for each group.

My thinking: *I am impressed that in this class of twenty-eight students, only seven students come up for materials. Everyone seems to know her or his job. They have done this sort of work before.*

Ms. Parker explains that she would like each group of students to place their empty cup in a basin, fill the cup with water to the very top, and then carefully place the metal washers in the cup, one at a time. "How many washers do you predict can go into your full cup of water before the water spills over?"

As the groups make their predictions, Ms. Parker reminds the students to think about the constants and variables in this experiment. "What are you going to keep the same? What will you change?" The

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TABLE 2.1 Data from the Experiment in Ms. Parker's Class

Group Number	Number of Washers	
	Prediction	Actual Result
1	4	14
2	3	15
3	5	12
4	4	13
5	2	14
6	7	15
7	4	13

students discuss how important it is for the *same* person to put the washer in the water each time. "Why is that important?" Ms. Parker asks. The students respond that if the same person puts the washer in, it will be easier to keep the procedure identical. Ms. Parker then says, "How should we place the washers in?" One student describes a way of sliding these metal circles in on the edge of the filled cup. All other group members need to look carefully at the water level as the washer goes in each time. Ms. Parker says that keeping the procedure the same each time helps the experiment to be a fair test.

Shondra asks what this experiment has to do with her water strider question. Ms. Parker says that she hopes the class will be able to help Shondra answer her question when the activities are completed.

My thinking: *I appreciate the way Ms. Parker holds out the expectation for Shondra that her classmates—not Ms. Parker—will collaborate with Shondra on the water strider question.*

After making their predictions, the students test them by sliding their metal washers into the cups. In every group, the students notice a difference between their predictions and their results. When the data are collected, the columns look like Table 2.1. One group asks Ms. Parker if they can try again. "Of course," Ms. Parker replies, and other groups follow suit. In their second try, the students adjust their predictions, but the results remain approximately the same.

Ms. Parker asks, "Why are the results slightly different from group to group and from one try to the next?" Students discuss how easy it is to start off with a little less or a little more water and so that is a variable.

My thinking: *By interrogating the data, Ms. Parker is reminding the students that there is a range of acceptable answers.*

Now Ms. Parker asks the students about the observations they made as the washers went in. "What do you think is happening to the water?" One student responds, "The water level rises." Another offers, "The water looks like a dome." Another student says, "It looked like it was never going to spill over; it just kept getting higher and higher." Lanie says, "It's like the water has a skin." Henry blurts out, "I know what happened. It is *surface tension*."

At this point Ms. Parker makes a circle on the whiteboard in the front of the room and writes the words "Surface Tension" inside. "Henry," she asks, "can you say more about surface tension? What do you mean by that?" Henry says that he is not exactly sure what it is, but "it's like when water sticks together." Ms. Parker then asks, "What were some of your observations when you placed the washers in the cup of water? What did you notice?"

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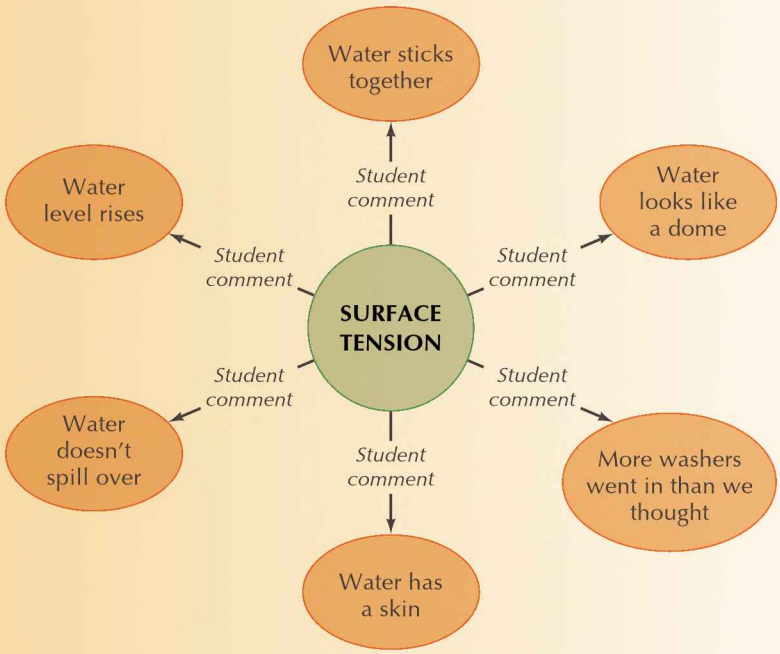

FIGURE 2.1 The concept map for "surface tension": initial stage

Ms. Parker records all the students' responses on the whiteboard. From the circle labeled "Surface Tension," she draws arrows out to other circles or ovals that contain all the comments the students have made about the water and the washers. As shown in Figure 2.1, Ms. Parker is making a **concept map** with Henry's phrase "Surface Tension" in the center. (This is just one use of a concept map; we can call this a "thinking map.")

Ms. Parker's thinking: *Although there is a complex explanation for surface tension, Ms. Parker is confident that the students can grasp the concept with her guidance. The concept map will help represent and develop their thinking. It is a way of scaffolding the students' ideas.*

As Ms. Parker creates the graphic, she steps back and asks the students to discuss the ideas they have offered within their groups and see if they can come up with further ideas about why the water behaves in this way at the surface. Suddenly Josh calls out, "It's like Henry says. It's surface tension." Ms. Parker responds, "But what does it mean for water to have surface tension?" The class is unsure. Shondra is beginning to get the idea that surface tension is behind the explanation for the water striders. Ms. Parker now encourages the students to do some research about surface tension on one of the networked computers in the classroom.

Further Experiments and Discussion

The next day, Ms. Parker asks the students to work within their science groups again and brainstorm ideas about surface tension. She also invites them to redo the water-and-washer activity but using pennies in place of washers. One group places forty-two pennies in a cup of water before it overflows! Some groups draw pictures of water molecules; other groups retry the washer activity. Using both their research and their experience, they offer some ideas in discussion with Ms. Parker. These form a foundation for understanding what surface tension really is.

The speaker in each group then reports the group's thoughts about surface tension to the class. As the speakers do this, Ms. Parker places the ideas in another level of the concept map. Ms. Parker herself then offers a comment that reinforces the research that some groups have done: "Water," she notes, "is made of tiny particles called molecules." She places this comment on the board as well,

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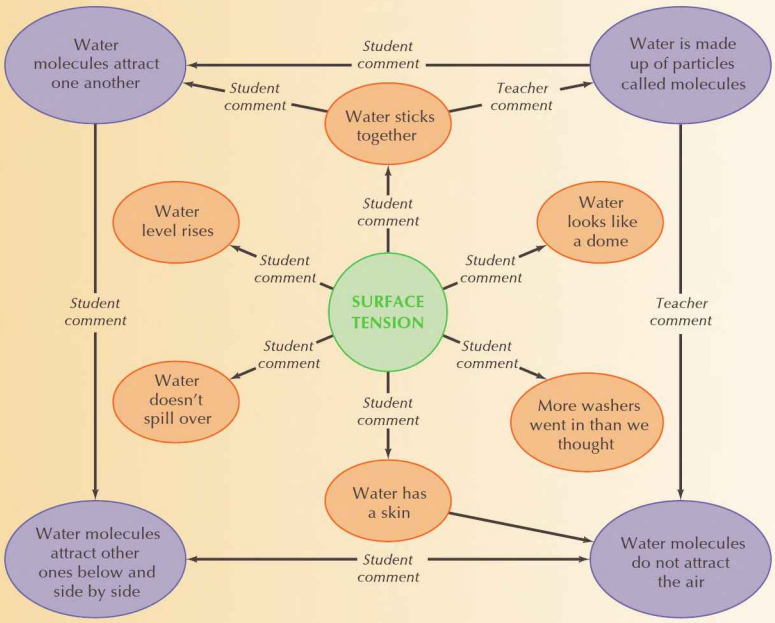

FIGURE 2.2 The concept map for "surface tension": a later stage

connecting it with an arrow to Henry's idea that water sticks together. Shondra's group then says that "Water molecules attract one another." Next, Henry's group shares the idea that "Water molecules do not attract the air." Ms. Parker asks the students to think about how this affects the water at the surface. Lanie's group has drawn circles and arrows showing the molecules of water at the surface holding on to each other and to the ones below them. Ms. Parker writes this idea, too, in a bubble on the whiteboard and links it with a line to the related comments. Now the concept map looks like Figure 2.2.

> ***My thinking:*** *I admire the way the concept map expands through the negotiations that occur between Ms. Parker and the students and among the students themselves. It becomes a visual record of the scaffolding of their ideas as they approach understanding.*

After the groups have all reported, Ms. Parker asks Shondra if she understands why the water strider can skip on the surface of the water. Smiling, Shondra says, "It's like the water molecules hold on tighter to each other at the surface of the water and that makes the water like it has a skin." Ms. Parker adds, "This helps the water strider skip across the water without falling under."

More Challenges

The following morning, students enter Ms. Parker's classroom and are challenged with another opportunity to explore the properties of water. The materials managers are asked to get plastic cups, basins, and square pieces of cardboard (about 3 inches on each side). Ms. Parker then asks each group of students to fill a cup of water to the top and cover it with a piece of cardboard. Holding the cardboard on the top of the cup with one hand, they are to invert the cup over the basin. The children gasp, "Won't it spill?" "If it does, that's OK," remarks Ms. Parker; "you have the basin under it." She then encourages the students to try this exploration and to experiment with different amounts of water in the cup.

Squeals of delight and frustration fill the room as students explore the inverted cup of water. Most of the time, the water remains in the cup, even with just the flimsy piece of cardboard on the bottom

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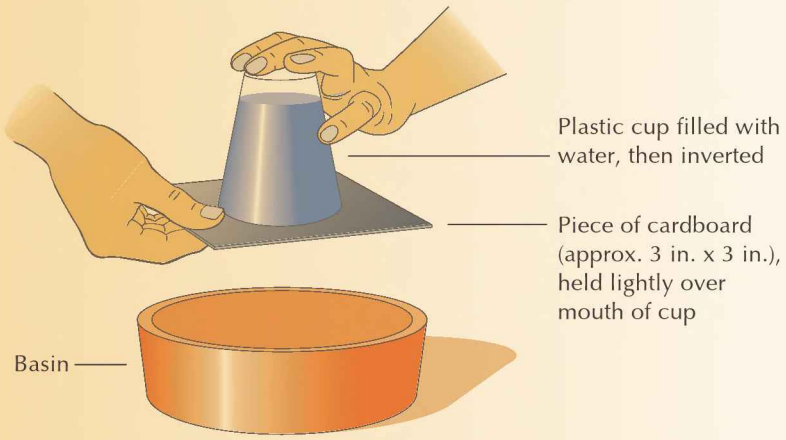

FIGURE 2.3 A surface tension experiment

(see Figure 2.3). Ms. Parker asks each group of students, with the help of the student serving as their group director, to come up with a theory about why the water does not spill out of the cup when it is turned upside down.

Students discuss this question in their groups, and each speaker reports the group's ideas. The following three explanations emerge:

1. The water sucks the card to it.
2. The air is pushing the card up and holding it there.
3. The water molecules at the surface are attracted to the water molecules that seep onto the cardboard, and the surface tension of water keeps the card and the water in place.

The students look to Ms. Parker for the right answers. Instead, she invites them to do another activity.

The students gather foil pie pans (one for each group), a pepper shaker, and a small cup of liquid soap. In each pie pan they place about 5 centimeters of water. They sprinkle the pepper on the surface of the water and observe as it clumps on top of the water. One student is instructed to dip her finger into the liquid soap and then place her finger in the pie pan. Suddenly, the pepper scatters—it appears to "run away" on the surface of the water to the edges of the pan. Then the pepper flakes begin to sink. Students are excited at this dramatic response.

Once again, Ms. Parker asks the students to discuss what happened and offer their own theories. This time the students have a plausible explanation. Each group says that the soap affects how the water acts at the surface. Two groups decide that the soap "breaks the surface tension of water."

Ms. Parker sends the students to the Internet again to find out how this happens. Students find out that soap works by reducing surface tension. Soap molecules have two very different ends. One end likes to dissolve in water and the other in oil. When you add soap to oily water, it happily mixes with the oil because the oil-loving part of the soap is on the top of the water surface, facing out. Thus, grease will dissolve in soapy water and get rinsed away.

Ms. Parker asks, "How can we test our theories for why the inverted cup of water did not spill?" Students decide to test the surface tension theory by inverting a cup of *soapy* water that has a cardboard square over it. They find that the soapy water has less surface tension, and the cardboard square holds for a much shorter time.

Ms. Parker informs the class that "Many people think the cardboard is held on by the air pushing up on the water. It is a common idea, but you have come up with a better one. You have shown how powerful the surface tension of water is and how that is responsible for holding the card."

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Just before the class ends, Lanie says, "Can we do the washers in a cup of water again, with soapy water this time?" "That is a good idea; let's try that tomorrow," Ms. Parker responds.

The Teaching Ideas behind This Story

- When the class observes a new phenomenon, the water strider, and becomes fascinated by it, Ms. Parker honors the students' interests by creating a series of related science experiences. By helping students explore their own questions, she encourages them to go further in their investigations.
- Notice that Ms. Parker does not answer Shondra's original question but promises that the entire class will address it.
- To help the students' group work go smoothly, Ms. Parker has set up clearly defined tasks for each group member. In this model, the *materials manager* collects and returns materials for the group; the *recorder* keeps track of data; the *speaker* reports on results and asks the teacher and other teams' speakers for help; and the *director* makes sure that the team understands the investigation and completes the tasks. You will read more about group structure in a later chapter.
- While she honors Henry's "right answer" about surface tension, Ms. Parker knows that she has to negotiate the meaning of this term with the students.
- In this context, concept mapping is a *mind tool* that can help students understand the *why* of something. It builds on the students' experience, helping to form a structure for discovering the underlying reasons for surface tension.
- Notice that Ms. Parker gives simple, clear instructions and no handouts. She encourages students to use the Internet for research, and she also encourages them to test their own theories with direct experiments.
- The students' use of the Internet reflects guidelines from the NETS-S (International Society for Technology in Education, 2007). The way the students use technology is particularly important because students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources.

The Science Ideas behind This Story

- Water molecules have two hydrogen atoms and one oxygen atom, as indicated by the chemical notation H_2O. The extraordinary stickiness of water is caused by the two hydrogen atoms, which are arranged on one side of the molecule and are attracted to the oxygen atoms of nearby water molecules in a state known as "hydrogen bonding."
- Within the water, away from the surface, every molecule is engaged in a tug of war with its neighbors on every side. For every "up" pull there is a "down" pull, for every "left" pull there is a "right" pull, and so on. The result is that any given molecule feels no net force at all. At the surface, however, things are different. There is no up pull for every down pull because, of course, there is no liquid above the surface. Thus, the surface molecules tend to be pulled back into the liquid.
- If the surface is stretched, it becomes larger in area, and more molecules are dragged from within the liquid to become part of this increased area. This "stretchy skin" effect is called surface tension. Surface tension plays an important role in the way liquids behave. The surface tension of water is what gives the shape to raindrops.
- The water strider, also called a pond skater, is an insect that hunts its prey on the surface of still water. It has widely spaced feet rather like the pads of a Mars lander. The water strider's feet depress the skinlike surface of the water beneath them. But the insect is buoyed up by a combination of its water-repellent hairs and the surface tension of the water. Water striders and their kin are relatively common insects.

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Connections to the Next Generation Science Standards

- **NGSS DCI: MS-PS1-4: Structure and Properties of Matter:** Gases and liquids are made of molecules that are moving about relative to each other. In a liquid, the molecules are constantly in contact with others.
- **NGSS SEPs:** Ms. Parker's students *planned and carried out investigations; used mathematics and computational thinking; asked questions and defined problems; analyzed and interpreted data; constructed explanations; engaged in argument from evidence;* and *obtained, evaluated, and communicated information.*
- **NGSS CCs:** The crosscutting concept of *structure and function* is seen here with the water striders as structures can be designed to serve particular functions by taking into account properties of different materials.

Exploring Further

If you were teaching this lesson about the surface tension of water, you may want to understand answers to the following questions:

- How does the structure of a water strider help it move?
- How does surface tension relate to a frozen skating pond?
- Where should Ms. Parker go next with this lesson on surface tension?
- Can you think of other ways to use concept maps? (In Chapter 13 you will find another illustration of concept maps.)

2-6 Students as Knowers

concept map
A diagram for developing an understanding of relationships between ideas. A concept map consists of circles or boxes that are called cells and that contain an idea, a selected term, or a question. The cells are linked with labeled lines that explain the relationships.

Teaching science requires *both* information *and* guidance from the teacher in order to help students learn. One of our goals is to help students become autonomous learners—to take charge of their own learning by performing tasks and making meaning of those experiences. We also know that there is a profound difference between acquiring information and gaining true understanding.

This chapter has demonstrated that building scientific knowledge requires us to engage in an active process of meaning construction in which we explore our own questions and test our own ideas. For students, this means that they become invested in seeking their own answers. The answers they seek enable them to fit their new ideas into their already existing conceptual framework—their prior knowledge.

Understanding how students learn science provokes us to find teaching strategies that honor students' ideas and create safe, open spaces in which they can create their own meanings. This is not the traditional notion of science teaching. For many people, it requires a shift in thinking. Rather than simply passing down or transmitting information through one-way communication, the teacher creates a forum for two-way or "multiway" exchanges, mediating the students' progress on the path to their own deeper understanding. To do so, the teacher must provide an appropriate context for learning and a setting in which students' own questions and ideas emerge. The teacher's role includes the following:

- Engaging students in concrete experiences
- Encouraging them to express their ideas about what they observe
- Listening seriously to those ideas and considering how they are based on the students' prior knowledge
- Asking probing questions about the students' thinking—an important technique because students usually have alternative conceptions that ought to be modified

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- Encouraging the students themselves to reflect on their ideas
- Scaffolding students' learning by:
  - Offering additional possibilities, such as other possible avenues of thought for students to explore, further questions to consider, new information on the topic, and new connections to make with their daily experience
  - Suggesting new experiments and providing opportunities for students to carry them out
  - Repeating this process as the students have further experiences, so they continually build new ideas and refine their old ones

The following poem in two voices helps to express the ideas we have developed in this chapter. The voice on the left side represents some traditional notions about science teaching. The right side represents the kind of approach that I hope this book will foster:

I teach science to students.	*I do science with students.*
I provide information.	*I provide experiences.*
I seek to control the lesson.	*I watch the lesson unfold.*
I like it when my students explore my *thinking.*	*I like it when my students explore* their *thinking.*
My students ask what they should be observing.	*My students trust their own observations.*
My students memorize facts from each lesson.	*My students reflect on ideas from each lesson.*
My students know the science ideas for the next test.	*My students connect the science ideas to their lives.*
My students know that science has all the answers.	*My students know that science helps find some answers.*
I teach science to students.	*I do science with students.*

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CHAPTER 3

Engaging Students in Science and Engineering Practices

Next Generation Science Standards

- **Crosscutting Concepts:** 1, 2, 3
- **Disciplinary Core Ideas:** 2-PS1.A, 2-PS1.B, 4-PS3.A
- **Science and Engineering Practices:** 1, 3, 4, 5, 6, 7, 8

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 3-1 Discuss the connections between multistation activities and the NGSS SEPs.
- 3-2 Examine the use of science notebooks in school science.
- 3-3 Design a five-station science "circus."
- 3-4 Connect technology to science as practice.
- 3-5 Relate school science to family science.

Reflection

To Think About:

- Do you ever predict the day's weather from your early-morning observations?
- Can you remember diagnosing a sick pet, a child, or a sibling on the basis of the symptoms you noticed?
- Did you ever vary just one ingredient in a recipe and come up with a new dish?
- Do you ever shop at the supermarket by arranging your grocery list according to the aisles in the store?
- Do you keep records of your expenditures and then sort them according to categories? Do you have a separate notebook for these entries?

3-1 Science and Engineering Practices: Using Multistation Activities

People who regularly engage in scientific activity or engineering design employ practices that help them gain information about the natural world. As we noted in Chapter 1, these scientific and engineering practices are often used in our daily lives, though we do not "code" them as scientific. Employing them on a planned and regular basis is what makes scientific activity different from ordinary activity. This is the essence of what we mean by "science as practice." It is important to remember that scientific thinking is "a complex intertwining of knowledge of the natural world, general reasoning processes, and an understanding of how scientific knowledge is generated and evaluated" (Duschl et al., 2007, p. 152). The science and engineering practices require several skills that are sometimes called "process skills or science skills." If the purpose of the activity is to answer a question, the students are doing science; if the purpose is to define a problem, students are doing engineering. While helping students gain experience with scientific and engineering practices, keep in mind that they bring their prior knowledge and their daily life experience to the tasks.

In this chapter, we explore a multistation classroom environment that provides students and teachers with science and design activities in which they must use certain skills to resolve a question or solve a problem. By a "station" I mean simply a desk, a table, or any other special area in which an investigation is described and materials are provided. By examining this environment and thinking about how it works, you can become more familiar with the ways in which students develop the skills of scientific study and use them to solve problems.

Multistation science activities are often developed around a content area theme, such as "states of matter" or "living things." In this chapter, however, we will look at an example in which the content areas of the stations are unrelated to one another. In other words, the context for each problem-solving activity is provided by the scenario created at that particular station. The organizing principle, in this case, is "using the skills of science to solve problems." Because, in addition to obtaining and evaluating information, *communicating* information is a significant scientific practice, we need to consider how students engaged in

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such activities can record their findings. Writing and drawing are important aspects of making observations and collecting data.

3-2 Science Notebooks

How and where do students record their science findings, draw their pictures, and explain their reasoning? Notebooks are an excellent choice. Scientists have always used notebooks to document their work, and they are also effective tools for students.

In Chapter 1 we discussed the use of science journals as a vehicle for exploring nature and recording observations, ideas, and questions, and I urged you to begin a science journal of your own—a personal journal focused on nature and the natural events you encounter in your daily experiences.

science notebook
A notebook in which students record their observations, reflections, questions, predictions, and conclusions during a science investigation.

Like a journal, a **science notebook** integrates writing and science, but it is more carefully structured as a thinking tool for students. In a systematic way, teachers can use students' science notebooks as part of the classroom science instruction. By helping students to structure their contributions to the notebook—for instance, by using prompts and sentence starters—the teacher scaffolds the students' learning.

A student science notebook is more than a collection of data or facts. It is a record of the student's reflections, questions, predictions, and conclusions. Writing is one way that students express the science ideas they are learning in their own words. This facilitates sense making and what we referred to in Chapter 1 as metacognition: being able to reflect upon what you know. Overall, as students use their science notebooks, they are enhancing their scientific reasoning skills and making meaning of the experiment, activity, or observation in which they are engaged (Klentschy, 2008).

There are many structures that teachers use for student entries in notebooks. There are also many types of notebooks. Often elementary and middle school science teachers use standard composition notebooks (those black-and-white marbleized notebooks). For the fourth-grade class described in the next section, the students were asked to set up a page in their science notebooks for each activity, following the organization shown in Figure 3.1. In Chapter 13 we will examine how science notebooks may be used to assess student learning.

Recall the scientific and engineering practices that represent an important dimension of the Next Generation Science Standards (NGSS Lead States, 2013). As seen in Figure 1.1, these range from asking questions to using mathematics and computational thinking to planning investigations and developing models. As you read the descriptions of each station in the science circus activity of the

FIGURE 3.1 A suggested structure for students' science notebooks for the multistation "science circus" activity

Date: _____

Station Number: _____

This station is asking me to _____

What do I think? _____

Drawing and Observations:

Some Conclusions: _____

This activity reminds me of _____

Professional Resource Download

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fourth-grade class at Mount Holly Elementary School, reflect on which of these practices are required to satisfy the challenges posed at each station. The scientific and engineering practices capture the essence of how the scientific community works to generate knowledge (Duncan & Cavera, 2015). Notice that there are several practices—plural—because there is no single method in science. Rather, there are many methods that converge to answer our questions about the natural world.

3-3 A Science Activity "Circus"

If you have ever been to a circus, you have noticed how many different things are going on at the same time. In three-ring circuses, a variety of entertainment acts occupy the rings in the center, while jugglers, clowns, and people on stilts walk around the periphery. It is quite a busy place. One hardly knows what to look at first. For students, these events create a world of excitement that they want to explore.

A friend of mine introduced me to a multistation classroom activity that she labeled a "science circus" because many activities were occurring simultaneously. I said, "When I think of a circus, I think of disorder." "On the contrary," my friend remarked. "It takes a great deal of organization to plan an activity where students are all at different places at the same time" (Abder, 1990).

science circus
A science activity that consists of several stations at which the visitors are asked to perform certain tasks and record their results or reactions.

A **science circus** is not quite as complicated as a real circus. Contained within a single room, the science circus consists of several stations at which the visitors are asked to perform certain tasks and record their results or reactions. It is circus-like because many different activities are going on simultaneously, but it is far from chaotic.

Each time I set up a science activity circus, it looks different. I try to use materials common in daily life and to create a scenario that invites students to explore them and come up with their own ideas. Often, too, I situate the activities in a personal context that is related to my own experience—a context I hope the students will recognize and share. It is always important to provide a rich context for the science stations so you are not pacing the students through science activities just for their own sake. The experiences must be constructed in a way that makes a connection to a larger idea or a personal story.

In the following story, I describe one typical science activity circus that I helped create, but keep in mind that the potential for different activities is practically infinite. Notice also that the stations try to arouse in the students a *need to know*, giving them a strong reason to use their science skills. As you explore these stations, you may be reminded of instances in which you have satisfied your own need to know by using the skills of science.

After seeing how the science activity circus works, we will explore the particular scientific and engineering practices connected to each station. As you read, think about how *you* would describe the skills that the students are developing.

SCIENCE STORY

The Science Activity Circus Comes to Mount Holly

I am visiting Ms. Markon, a new teacher at Mount Holly Elementary School. I have been her teaching supervisor, and today we are setting up a science circus in her fourth-grade class. We have used the students' lunch break to prepare the tables in the room. The students are aware that they will be returning from lunch to find that their room has been transformed.

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When the students come in, they discover several tables, each with a different object or collection of objects and an index card, also called a *task card*, with instructions and questions on it. They are delighted with the transformed classroom and eager to begin. Because it is important for students to share ideas with each other, Ms. Markon asks each to work with a buddy as they explore the stations in the science circus. Each pair of students is assigned to a different station to start. They are instructed to visit each of the stations, spending between five and ten minutes at each stop. As the students explore the stations, I have the opportunity to interact with them.

An Old Log

At one station, the table holds an old log from my backyard. It comes from a birch tree that was felled in a storm several years ago. The log is very dry, but its thin, whitish bark is still intact. It is about 2 feet (60 cm) long and has a diameter of about 5 inches (12.5 cm). One end of the log is rough where it broke off from the rest of the trunk. The other end is smooth because the log was sawed for firewood. In the middle of one side of the log is a large, oval opening, probably made by the gradual pecking of a large-beaked bird.

Ms. Markon and I do not tell the students everything we know or surmise about the log. Instead, we refer the students to the index card on the table next to the log. It reads as follows:

> This is a piece of a tree trunk that I found in my backyard. Can you explore this piece of trunk and try to figure out what happened to it?
>
> What are all the things you observe about this tree trunk? What are some of your ideas about how it got to look this way?

The children handle the small log and record their ideas. Working in pairs, they talk about the log and how they think it got to be here in our science circus. One girl takes a marble from a neighboring shelf and drops it into the hole in the log. When I notice her doing that, I walk over to watch more closely.

"Oh!" she exclaims. "I'm sorry I took the marble!"

Surprised that she believes she has broken some rule, I reassure her that I think she has a great idea and that I'm just curious about what she wants to find out.

"I was just trying to see if the hole in the log went all the way through," she says. "It doesn't."

> ***My thinking:*** *The girl's reaction dramatically illustrated how rule-bound students become after only a few years in school. I reminded myself to rejoice in those moments when students use their creativity to explore.*

The students readily notice the differences between the two ends of the log. "Somebody sawed this," says one. "This looks like it broke off," another student suggests, looking at the other end of the log. "I bet a woodpecker did this," still another student offers, looking at the large hole inside which the marble has been rolling around. They draw pictures of the log in their science notebooks. They also record the title of the station and their observations and ideas about the log.

The Soda Can

On another table we have placed a soda can that was left in a car on a very hot summer day. The heated gas bubbles in the soda exploded the lid of the can at its seams and puffed out the bottom. The can is empty now, but it looks quite unusual. The lid is still attached at one point along the edge. The index card at that table reads:

> On a very hot summer day, I left my unopened soda can in the back of my car. Several hours later, when I returned to my car, the soda was all over the car seat and this is what the can looked like. What do you think happened?

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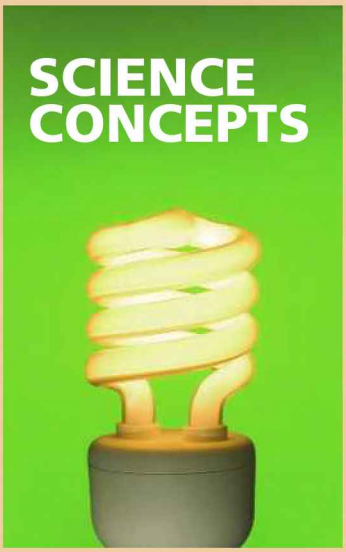
Effect of Temperature on Liquids



At the soda-can station, students have the opportunity to learn what happens when we heat or freeze a liquid. When a carbonated liquid is kept in a very hot place, the carbon dioxide gas dissolved in the soda water becomes less soluble as the temperature increases. Heat energy increases the speed at which the liquid and gas particles move. The faster the gas particles move, the more frequently they hit the sides of the container and the greater the pressure. This pressure can eventually burst the seams of the can.

As one of the students in the story realized, the same kind of thing can happen when a soda can is frozen. Even though most liquids contract when they are cooled, water-based liquids like soda water start forming crystals when they begin to freeze, and these ice crystals occupy more volume than the original water. As the carbonated liquid occupies more space, it can burst through the seams of the can. This usually does not occur when soda cans are left in the freezer or out in the icy cold weather because a little space is typically left in the can that the freezing soda expands into. But many containers of water-based liquid that are filled to the top and sealed do burst when frozen. Hence, if the students inferred that the can was left either in a freezer or in a very hot place, they were correct.

Listening to students brainstorm about this can is very interesting. "Once," says one child, "my mom left a soda can in the freezer by mistake, and this is what it looked like." Another child remarks, "It looks like it exploded." The students record their various ideas in their science notebooks.

My thinking: I am interested to learn whether the students make a connection between temperature and the behavior of liquids in a can. I'm using a real story from my experience, one that I hope they can relate to. Asking new questions about daily-life experiences is my way of engaging them in the task of problem solving.

Crazy Rocks

In a large plastic bowl on one table, Ms. Markon has arranged her rock collection, which consists of several kinds of rocks. She has collected these rocks from many different places, and they are of various colors, textures, sizes, and shapes. The index card on the table reads:

> When astronauts brought rocks back from the moon, the first thing the scientists did was to group them according to similar characteristics. This is MY rock collection. You may have a rock collection too. I started collecting rocks when I was a small child. When you explore these rocks, what do you notice? In what ways are they the same? In what ways are they different? How many categories could you place the rocks into? Where do you think I found these rocks?

The students love rummaging through these rocks. It is a fairly large collection, and they come up with categories like "bumpy," "smooth," "light colored," "dark colored," "shiny crystals," "no crystals," "stripes," and "no stripes." Some of these rocks may be ones the students have never seen before.

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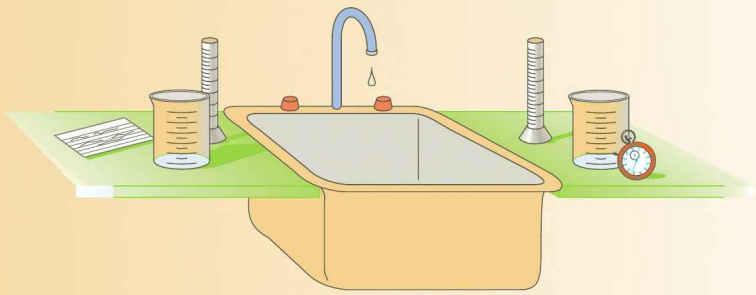

FIGURE 3.2 A dripping sink or water jug makes a simple but effective station in a science circus, stimulating students to observe, measure, and calculate

My thinking: Although many students could not relate to some of the rocks in the collection, most could relate to the idea of having a collection—at least an informal group of rocks that they had picked up here and there because they liked them.

The Leaky Faucet

This station is at the classroom's sink, where water is dripping slowly from the faucet. (If your room has no sink, you can use a large jug of bottled water with its own spigot and a basin to collect the dripping water.) Nearby are a stopwatch, beakers, and graduated cylinders (Figure 3.2). The card reads as follows:

> You may have seen a leaky faucet in your own home. Measure and write down the amount of water that drips from the tap in one minute. Work out how much water will drip in one hour. How would you find out how much water will drip in one whole day?

As I watch the pairs of students, I remind them to write their plan in their science notebooks before carrying it out. Then I continue to watch and listen as they solve the problem.

My thinking: I am interested in understanding how the students will figure this out. What will they do? What units will they use? What will their decisions tell me about their prior experience and the ways they think?

Many of the students are surprised to learn that as many as 7,200 milliliters of water can drip from a leaky faucet in one day if only 5 milliliters drip out in one minute. The next day, Ms. Markon brings in empty liter bottles, and the students help her stack seven of them up to see what 7,000 milliliters looks like. Several of them suddenly realize why their parents nag them to turn the water off. Several remember hearing that in some parts of the world fresh water is a scarce natural resource.

The Penny in the Pie Pan

At this station there are some pencils and a few pennies on the table, plus an aluminum foil pie tin that is half filled with water. The students read the following:

> Many of us like to swim. Have you ever noticed that your hands and feet look different when they are under water? Today we are going to submerge a penny in the pie tin of water. Before doing that, take your pencil and trace the penny in your science notebook. Now draw what you think the penny will look like when you put it in the water. Now place the penny in the water. What do you notice?

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The students trace their pennies with their pencils and sketch their predictions. When they see the pennies in the water, they are often surprised. "I didn't know it would look so big," one boy exclaims. They record their observations in their science notebooks.

My thinking: At this station, Ms. Markon and I want to engage the children in an activity that invites them to look at ordinary materials in a different way. Pennies, water, and pie pans are commonplace items. Making the connection to swimming is another way to provide a personal context for the activity.

Three Types of Soil

At this station there are no materials at all. This is a "thought experiment." The card reads as follows:

> Imagine you have three different types of soil. How would you determine which soil holds the most water? What will you keep the same? What will you change?

The students spend a long time at this station. They brainstorm a way (or several ways, sometimes) to figure out the problem. When they decide on a way to solve the problem, they write it in their science notebooks. Here is an example from two of the fourth graders:

> Use three cups. Put three holes on the bottom of each cup and stand each cup in a pan—like a pie pan from the last station. Add each soil to a cup [one type of soil per cup] and then put the same amount of water in each cup. Wait one hour. Measure the water that drips out the bottom. The cup that doesn't drip out too much water has the best soil.

I ask this pair of students, "How big is each cup?" I want them to understand that we need to keep the size of the cups the same. Then I ask, "How much soil do you put in each cup?" I want them to see that they should use exactly the same amount of each soil. They decide to use half a cup of each soil. Next I ask them, "How will you measure the water that drips out?" The two students explain that they will pour it from the pie pan into a measuring cup.

On my next visit, I bring in three types of soil, paper cups, and measuring cups, and these two students try their experiment. It works! We examine the soils for size of particles and color. We determine how the soils are the same and different.

Another pair comes up with a different solution. They will also use paper cups, they decide, but they won't punch holes in the bottom. Instead, they will add the same amount of water to each type of soil and wait fifteen minutes. Then they will take three sheets of paper toweling, and on each sheet they will empty one of their cups, dumping out both the soil and the water. They have reasoned that whichever paper towel is the wettest will contain the soil that can hold the least amount of water.

"How much water will you add to each cup?" I ask.

They haven't thought about that—just that each cup would get the same amount of water. They think a little more about their plans. On my next visit, they carry out their experiment. They have decided to add one-half cup of water. But they find that their cups are too small for that amount, so they need to add less. They try again.

My thinking: I particularly like thought experiments, especially ones that involve experimenting with materials that the students can readily imagine. In this case I used soils because most children have had plenty of experience with dirt! Also, of course, it was easy for me to bring samples of three types of soil to the classroom on my next trip. It is important for students to learn that design, and specifically designing an experiment, is an ***iterative process****. You try it out, see what happens, alter your plans for the next attempt and do it again! Designing experiments is an integral part of doing science with students.*

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The Weather Station

This station has a wireless laptop set up to access an Internet weather site. This and other weather sites provide statistics, photos, and explanations of unusual weather events. At this station the card reads:

> Compare the air temperature and weather conditions for San Francisco, California; Chicago, Illinois; and New York City. In what ways are they the same? In what ways are they different? How do they compare to Mount Holly? Set up a chart in your science notebook that organizes these data.
>
> Which of these cities would you prefer to be in today? Explain your reasons.

The students use the Internet site to gather data that they then record in their science notebooks. They need to manipulate the computer to obtain the information they are seeking.

My thinking: The relatively simple task of recording data from a website is one way the students can become familiar with using computers as a tool for scientific study. This same activity engages the children in map reading, which gives them experience with another significant tool. I like to personalize the activity by asking the students to choose the city that has their favorite weather.

The Teaching Ideas behind This Story

- The science activity circus stations provide opportunities for students to practice using scientific skills. While doing this, they also gain practice with investigations that generate some original thinking.
- Notice how curious the girl was at the station with the small log. When she acted on her curiosity by placing a marble in the hollow, she was momentarily unsure if she had done the "right thing." Often youngsters are timid about trying out their ideas, fearing they will be "wrong." Teaching science invites students to overcome that fear.
- At the station with the thought experiment about three types of soil, there were at least several possible "right" answers. Challenging students to solve a "How would you find out?" problem invites multiple responses as students personalize the problem and design solutions. Notice how, through my questions, I prodded them into setting up a fair test by pointing out how important it is to keep the experimental conditions the same. Notice, too, that at a later time I brought different soils to class. Thought experiments can be frustrating to students if the experiments cannot actually be tried.

The Science Ideas behind This Story

- The activities of the science activity circus are designed to give students practice with several skills. Most of the stations involve more than one scientific or engineering practice and more than one set of skills.
- At the station with the log and at the soda-can station we are asking the students to *construct explanations* using the skills of observation and inference. An **observation** is all of the information we can gain about an object or an event by using our senses. An **inference** is a reasonable statement about an object or an event that is based on an observation. We make observations with our senses and use our minds to make inferences—to really think about something. For instance, what happened to this tree trunk? Why does it look this way?
- An inference may or may not be provable. In science, if an inference or a guess is stated in a way that allows it to be tested, it is called a **hypothesis**.
- When the students explored the rock collection, we were asking them to observe in a particular way. This skill is **classifying**—sorting objects or ideas into groups according to similar properties. Classifying is a basic skill that human beings use to try to make meaning of the natural world and all its diversity. We use classifications in all of our thinking. Classifying the rocks into different groups required that students *argue from evidence* to justify their groups.

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- The leaky faucet station involved **using** *mathematics and computational thinking*. Here, the students had the opportunity to work with tools that helped extend their abilities to observe. At this station, they used a stopwatch, graduated cylinders, and beakers, which are helpful for **measuring** time and volume. Other useful measuring instruments are balance scales, spring scales, thermometers, and meter sticks. Your students may also have the chance to use probe devices connected to a computer.
- When they recorded their measurements, the students were *obtaining information*. In school science, data include many different types of information, and students can record them by using words, numbers, graphs, drawings, or a computer program.
- At the penny and pie-pan station, the students were asked to **predict** what they thought the penny would look like under water. Then, after they dropped it in the pie pan, they *analyzed* their observations and compared them with their predictions.
- At the station without materials, which we called a thought experiment, the students were asked to **plan an investigation**. To do this, they had to recognize that testing ideas involves *controlling variables*. That is, they had to ask themselves, "What do I keep the same, and what do I change?" When we do science, we have to plan investigations where all variables but one are controlled. So if we want to find out which soil holds the most water, we need to keep the volume of the water, the amounts of the soil, and all other experimental conditions the same, changing only the type of soil. These are the attributes of a fair test.
- At the weather station, students were again obtaining and evaluating information and **recording data** that they had gathered.

Exploring Further

Think about a science circus station that you would like to create—perhaps one very different from the stations described in this chapter. If possible, plan it for a particular class with which you have had some experience. Then ask yourself the following questions about your plans:

- What scientific and engineering practices will students use to complete the task?
- How engaged will the students be in their own thinking? Will your station provide opportunities for them to ask their own questions? How can you promote their thinking?
- How can the station be relevant to your students' lives?
- What sorts of things do you expect to learn about the students from their questions, and how will this knowledge help you plan other science activities for them?
- How will you structure the entries in their science notebooks?
- How does this activity circus correlate with the new generation of science and engineering standards?

3-4 Technology Extends Our Senses

The practices of scientific exploration rely on our senses as well as on our prior knowledge and experience. Computer technology greatly enhances our capacity for making and saving observations and recording data, hence extending our senses. You saw a hint of this capacity in the weather-station activity, in which students used an Internet site to explore weather in three other cities as well as their own. They could also use a wireless handheld device like an iPad or an iPhone. There are many software programs that help students extend their senses as they engage in science as practice.

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iterative process
The act of repeating a process of design where the final result of one process or *iteration* is the starting point for the next iteration until an optimized solution or target goal is reached.

observation
Perception of an object or an event, using as many senses as possible.

inference
Reasonable explanation that we construct on the basis of our observations. Inferences sometimes lead us to set up further investigations.

hypothesis
An inference or a guess that is tested through a planned investigation or experiment.

classifying
Sorting objects or ideas into groups on the basis of similar properties.

measuring
Determining distance, volume, mass, or time by using instruments that indicate these properties (such as centimeter sticks, graduated cylinders, scales, or stopwatches).

predicting
Estimating the outcome of an event on the basis of observations and, usually, prior knowledge of similar events.

planning an investigation
Determining a reasonable procedure that could be followed to test an idea. This includes listing the materials needed, writing out the procedure to be followed, and identifying which variables will be kept the same and which will be changed.

recording data
Writing down (in words, pictures, graphs, or numbers) the results of observations of an object or an event.

probe
An electronic sensor, connected to a computer or other wireless handheld device, that allows the user to record real-time data about the environment.

3-4a Real-Time Data Collection Software

An important support for science learning is the use of measuring instruments with computer interfaces. Electronic sensors, usually called **probes**, connect to a computer or wireless handheld device, including iPods, iPads, or a smartphone with the appropriate software. These probes allow students to record real-time data about their environment. These probes come with instructions for downloading the software from the Internet. The probe itself can usually be connected through the USB port on your computer or handheld device.

Common probes include temperature, voltage, and motion sensors. The use of probes in an inquiry environment assists students in understanding important scientific concepts, such as heat and temperature. Data from a probe can also automatically generate a graph. Further, mobile applications for smartphones and tablets can automate data collection and capture images, sounds, and text. In Chapter 4, we will examine how urban sixth graders use a mobile app to identify local street trees.

In one third-grade classroom, the students were exploring whether heat is produced during seed germination. They were germinating seeds in plastic bags with wet paper towels and had inserted a temperature probe into one of the bags. This probe took the temperature of the air inside the bag every two hours over the course of five days. Collecting the data every two hours in a conventional way would have been impossible, as no one was around at night. The probe stored the readings on the computer, making the data easily accessible. Using this equipment, the students were able to collect data that showed that, as their seeds germinated, the temperature rose.

3-4a Using Video to Extend Observations

Because digital video is now commonplace, science teachers have discovered that video is an exciting technology for improving and extending the process of observation. Students can make their own videos of science experiments. Further, videos can record what happens when you are sleeping. Nighttime camera videos have helped students to learn what animals live around their school environment or how their classroom hamster delivered her babies. When a science teacher used digital video to record the popping of a water balloon, the students watched it in slow motion and saw things they could not have seen with the unaided eye. Their video helped them answer the question, "What really happens when a balloon bursts?" (With a water balloon, from which the water is expelled as the balloon pops, the bursting process is slow enough for the details to be revealed in a digital video.)

The *video microscope*, which uses digital technology to magnify images of objects, revealing a microscopic world on a computer screen, is a readily available tool that allows a class to examine microscopic organisms in real time on a computer screen or any other monitor. Some video microscopes have detachable digital cameras; others have all-in-one systems. There are many choices. Using this technology, one sixth-grade class observed the single-celled organisms in a small sample of water from a nearby pond. The water was set up on a slide of a video microscope that displayed its images on a computer screen. Because the technology allowed all the students to view the slide at the same time, the teacher was able to facilitate a conversation about the microorganisms with the entire class. Today, many YouTube videos are available for you to share with students. You can use digital video devices to record the students' investigations and upload them to the science videos currently on YouTube!

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3-5 Science in the Classroom and with the Family

If you answered "yes" to any of the "To Think About" questions at the beginning of this chapter, then you have been using scientific and engineering practices in your daily life. Making decisions about products, the weather, our health, and the state of our nutrition requires careful attention to what counts as evidence; how explanations are constructed; and how information was obtained, evaluated, and communicated, which helps us to be more aware citizens.

Asking questions and testing ideas in a planned and consistent manner is the foundation of scientific practices.

Through activities like the ones in the science activity circus, young children begin to build confidence in their abilities to understand the natural world. They learn to observe closely, sort things into categories, and ask how things are the same and how they are different. Even very young children can make predictions—"What will happen if . . .?" They come up with tentative explanations for their observations, and these inferences change as they get older. Children begin measuring by using string, centimeter sticks, and balance scales. They weigh objects using uniform masses like the teddy-bear counters in the icicles story from Chapter 2. As they mature, they begin to use standard units of measurement for distance, mass, and volume. By third grade, many students can design investigations, recognize variables, and control the experimental conditions. By middle school, students can plan and carry out a greater variety of investigations, including experiments that involve more than two variables and require them to record detailed data. At all levels, students are recording data in some fashion in their science notebooks, first through drawings and later through words, graphs, and numbers.

Remember that activities like those at the science circus stations succeed only if they generate students' questions and promote further thinking. The students' minds as well as their hands have to be applied. They will not learn to employ scientific practices merely by manipulating objects. The enduring learning occurs as a result of their brainstorming, discussion, reflection, and communicating of what they have learned.

3-4a Family Science Night

The concept of a science circus—several stations offering a wide variety of activities—can form the basis for an event that involves students' family members. Engaging adults in science experiences together with students is a way to not only bring families together but also to encourage a deeper interest in science and science-related activities. Moreover, research tells us that parents' attitudes affect their children's attitudes, and some adults' fears of science may have a negative impact on their children (Kober, 1993). By emphasizing the relevance of scientific activities *outside* school—in our students' everyday lives—we can help change those negative images of science.

family science night
A community-involvement activity in which students bring a significant adult or adults to the school to participate in inquiry-based science activities typically set up at stations in a large classroom or in the school cafeteria.

A **family science night** can take many forms (Photo 3.1). At one school I observed, the event was spread over two nights so as many families as possible would have the opportunity to participate. As parents and students filed into the school cafeteria, they picked up red booklets titled "My Family Science Notebook." The teachers had designed seven stations that invited participants to manipulate materials and use trial-and-error problem solving. The activities were carefully planned to stress process skills like the ones described in this chapter.

Each of the stations offered complete directions, materials, and questions to encourage higher-order thinking and discussion. Each activity corresponded to a page in the notebook on which the families could record or sketch what they were doing. The students were encouraged to act as the note takers for the family. The notebook also included questions to guide the students and follow-up activities to perform at home.

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Paul Conklin/PhotoEdit

PHOTO 3.1 Students share their understanding with their class and visiting parents.

At one station, families investigated how many drops of water could fit on the head of a penny and how a water droplet can become a magnifier. At another station, students listened to their heartbeats with a stethoscope, counting the number of beats in a fixed period of time, before and after exercise. At a third station, families explored the movements of garden land snails. Four other stations touched on other aspects of life science, physical science, and earth science.

All of the families' observations and inferences were recorded in their science notebooks, which contributed a great deal to the success of the evening. Families used their notebooks as a way to keep track of what they did and what they learned. Further, the notebook became a symbol both of science and of the family science night. At home, families could use their science notebooks to duplicate the science night activities.

Sometimes family science nights became an annual tradition. The teachers change the design of the science stations each year. Letters sent home with the students ask community members what they would like to see at the next family science event, which establishes an ongoing science link with the students' homes.

This story illustrates just one successful format for a community science night. You can design your own format and your own stations. The key is to engage students and their families in a genuine process of inquiry that relates to their own lives and challenges them to construct their own ideas.

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Boston Globe/Getty Images

CHAPTER 4

Scientific Explorations Inside and Outside the Classroom

Next Generation Science Standards

- **Crosscutting Concepts:** 1, 2, 4, 6
- **Disciplinary Core Ideas:** MS-LS2.A, MS-LS4.A, MS-PS1.A
- **Science and Engineering Practices:** 2, 4, 5, 6, 7, 8

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 4-1 Distinguish between the formal and informal science curriculum.
- 4-2 Reflect on the importance of students' experiences with the natural world.
- 4-3 Connect scientific study to the daily life of the classroom.
- 4-4 Understand the distinction between everyday observations and scientific observations.
- 4-5 Discuss how to use scientific data to provide evidence of ecological disruption.
- 4-6 Examine the goals and procedures for science field trips.
- 4-7 Discuss the significance of science centers in the daily life of the classroom.
- 4-8 Discuss how a classroom can reflect the science unit at hand.

Reflection

To Think About:

- How can informal science-learning experiences shape your knowledge of science?
- What natural event has been making headlines recently?
- Why do you think scientific study feels alien to many students?
- How does the region where you live adapt to changing climate conditions?
- How can environmental issues find their way into the elementary and middle school science curriculum?
- What items do you tend to collect? Do they include anything from nature? Can they find their way to a classroom science center?

We are living through a period of time in education when standardized testing and formal curriculum topics dominate the landscape of teaching and learning. Teaching elementary and middle school science is a wonderful way to engage students in creative and personally relevant topics about the natural world. This gives you, the teacher, the opportunity to make the science experience personal and locally relevant; and, depending upon the area in which you live, you can use natural events to promote science in the daily life of the classroom and to make connections to the region in which your school is situated and where your students live. In this chapter, you will see how one middle school does just that.

Two of the stories described in this chapter were made possible through National Science Foundation Research Grants: NSF (Grant# 733269; 0918629) Ecology Disrupted (2009-2014) and (Grant #1221188), Unifying Life: Placing urban tree diversity into an evolutionary context. All views expressed are those of the author and not the NSF.

4-1 Two Types of Science Curricula

formal science curriculum
The explicit statement by a school or a school district of the science topics and methodologies to be implemented at each grade level.

Many schools follow a **formal science curriculum** that has been developed at the state or local level or that has been commercially developed and purchased by the school district. These formal curricula have primarily been put together with the guidance of the *National Science Education Standards* (National Research Council, 1996), the American Association for the Advancement of Science (AAAS, 1993) *Benchmarks for Science Literacy*, or state and local frameworks. Sometimes schools and districts adopt a formal science curriculum that

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has been developed by a commercial publisher. Now, there is a new generation of science and engineering standards that are emerging, and these new standards stress the importance of engaging students in creative experiences that allow them to design solutions to some of our vexing scientific problems.

When teachers use *only* the formal guidelines to design students' science experiences, they limit the topics of study to those addressed in formal curricula. Although those experiences may be good—and may make some topical connections to students' lives—they do not include experiences that are *unique* to a particular class in a specific geographic locale.

informal science curriculum
Science learning experiences that go beyond the formal science curriculum of the school or school district to include other topics and methodologies that connect to students' daily life outside the school. The topics might arise, for example, from spontaneous natural occurrences, local news events, or materials the students bring from home.

Science experiences that are unique and very personal make up what I call the **informal science curriculum**. In this chapter, you will see that this informal curriculum can be extremely important. You can think of it as a way to integrate into the classroom spontaneous natural events from the school's locale and science experiences that the students bring from home. In Chapter 2 you saw the informal science curriculum at work when Mr. Wilson brought icicles into class to teach students about changes in matter. Students can also study local objects from nature and even make collections of the plants they find outside the school.

I live in an area that usually receives 18 inches of snow a year. In the 2009 winter season, more than 80 inches of snow fell in my area. It was most certainly a subject for science exploration. When schools reopened from one of the snowstorms, one teacher brought in a huge bucket full of snow to her fourth-grade class and asked students to design a way to measure how much water the snowmelt would yield. This is what I mean by the informal science curriculum. Students designed experiments, used measuring devices, and studied an event in their locale.

This chapter explores a variety of informal science learning experiences and the ways you can develop them by using a classroom science center and field trips. We also see how Web-based materials can help a class explore environmental science issues that affect the students themselves and everyone else in their region. The Internet also makes it possible to explore regions well beyond our own home boundaries. First, however, let's look at some reasons why it is so important to make these connections between science and your students' daily lives *outside the classroom*.

4-2 The Importance of Experiences with Nature

Imagine small groups of students scattered about a natural area adjacent to their school. One group is identifying local plant life using a field guide. They are choosing plants that will be part of their Nature Gallery. Another group has a microphone attached to an iPod and is trying to record the sounds of cicadas for use in a podcast they are creating about how insects communicate. . . . Ultimately these are place based, meaningful, and active learning experiences (Bodzin, Klein, & Weaver, 2010).

Using the outdoors as a way to do science with students creates a classroom culture that values the natural world. This is so important at a time when many youngsters spend more time indoors, online, and playing computer games than they do outside, interacting with nature. Many scientists agree that there are serious health issues associated with spending excessive time indoors. For children and adults, these health problems include obesity, depression, and type 2 diabetes (Jones, 2008).

Thomas Berry, once described in *Newsweek* magazine as part of a new breed of "eco-theologians," said that "teaching children about the natural world should be treated as one of the most important events in their lives" (Berry, 1996). A large body of evidence suggests that immersing students in the local environment enhances their understanding of the natural world and enables them to develop an appreciation for nature that is necessary for stewardship of the planet.

The state of the environment, a controversial topic for many years, is currently receiving a great deal of attention as a result of rising global temperatures,

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depleted stores of natural resources, and disappearing flora and fauna. "Going green" has come to represent the ways in which individuals may change their daily practices to conserve energy, generate less waste, and understand the effects of their lifestyles on the quality of life on our planet. You can hardly read a newspaper or watch television without some reference to "green practices."

green science
The branch of environmental studies that includes the study of alternative and renewable energy, food webs, conservation, resource distribution, and the changes in world climate.

So what do we mean by green science? **Green science** involves teaching students about conservation, alternative and renewable energy, and sustainable practices that reduce each individual's environmental footprint—that is, the amount of natural resource depletion and waste generation in which we all engage as we go about our daily lives. It also refers to helping students understand the science ideas, or core concepts, that are the underlying causes of an environmental disruption to nature. It is one thing to label an "issue" an environmental problem. It is quite another to address the scientific evidence that tells us that, indeed, there is a problem.

Later in this chapter we will explore ways that elementary and middle school science teaching can help students develop a "greener" approach to everyday events. Just by getting students outside, we can help them develop an appreciation for nature.

4-2a Diversity Within and Without

Wherever your school is located, you will find enormous diversity in the nature around you. Often you can see some of it just by looking out your classroom window. You may find yourself amid the rich deciduous forests of the suburban or rural Northeast, close by the vast cornfields of the Midwest, or near the rocky shores of a coastal community. In the Southwest or Southeast, you may be surrounded by the dramatic flora and fauna of arid or tropical regions. Even at an inner-city school, you may find trees in the planting squares on sidewalks or dandelions breaking through the cracks.

You probably have a great deal of diversity among your students as well. They will notice different things in nature and respond to them in different ways. Consider the little dandelion in the sidewalk, for example. One student may see it as a sign of the stubborn persistence of plant life; a student with relatives in the suburbs may see it as a weed that ought to be exterminated. One student may come from a family who serves dandelion greens at meals; others probably have no idea that people would eat such a thing. One may think the dandelion flower is beautiful; another may think it ugly or not even recognize it as a flower. Whatever their particular reactions, your students' unique ways of experiencing nature provide a rich tapestry of science experiences that can become part of the life of your classroom.

By taking advantage of this diversity inside and outside your class—seizing the opportunities to make interesting connections between students' lives and the natural world around them—you can make your classroom a dynamic, vital place. Moreover, building these links stimulates learning in two major ways:

1. It helps students see the larger picture.
2. It helps students to see science as a way of knowing the natural world.

4-3 Seeing the Larger Picture: Content Plus Context

All students learn better if they can relate their school experiences to their daily lives. Recall what the opening chapter of this book said about the need to fit new concepts into our prior knowledge—a concept that the science stories in previous chapters have already demonstrated. Particularly in science education, however, many adults can recall learning the content without any context to which they could relate it. There was no larger picture, so to speak.

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As a result, these students "learned" science by memorizing decontextualized facts to pass tests and then forgot them afterward (as reported in science autobiographies; see Koch, 1990).

Today, even formal science curricula generally strive to find ways for students, especially young children, to relate science ideas to their lives, and the best curricula acknowledge that students' lives encompass a wide variety of activities, cultures, and home environments. By linking science to students' own, individual "larger pictures," we not only help them learn better, but we also help them use science ideas to understand events in their daily lives more fully. As we discussed at the beginning of this book, we are living in an increasingly complex world—one that requires its citizens to be observant, critical, and thoughtful about their immediate environment. Those who understand scientific ideas in the context of their daily lives have a head start in dealing with the issues that their lives present.

There are many ways to integrate scientific study of the environment into the daily life of your classroom. Yet even when learning about subjects critical to the world they live in—the water they drink, the air they breathe—students can be put off by a detached, fact-based approach. In this chapter, you will read about several ways in which teachers in ordinary classrooms integrate scientific understanding into their students' *own* natural environment. You will also see examples in which other branches of science, such as physical science and life science, are linked to students' experiences. We begin with how students in the sixth and seventh grades explored local urban trees as a way to understand biodiversity and common ancestry.

4-4 Making Observations of Local Trees: Understanding Common Ancestry

> *You see, but you do not observe.*
> —SHERLOCK HOLMES, *"A Scandal in Bohemia"*

In the last chapter, we invited students to stations where using their senses to make perceptions about the materials was key to taking next steps. But, as many researchers indicate, "on the surface, scientific observation is deceptively simple" (Eberbach & Crowley, 2009). So how do everyday observations become more scientific? Part of the answer lies in the context—the actual disciplinary frameworks that students are provided. The other part of the response is that everyday observers can be taught to observe more scientifically. The following story sets the stage for sixth-grade students to prepare to go outside in a Northeast autumn and observe the trees around the urban neighborhood of their school. As you will see, the teacher begins in the classroom with careful observations of acorns and then uses an iPod app called Leafsnap to go outside to scientifically observe local trees. This type of observation uses the app as a tool to examine attributes of the trees, their leaf structure, leaf arrangement on a stem, bark, fruit, and, depending on the season, their flower. It is autumn in the Northeast. The deciduous trees have not changed color yet, and the students walk by these trees daily and never notice them.

As you read the following story, ask yourself these questions: Why is the teacher engaging students in studying local trees? How is scientific observation different from everyday observation? What types of organizing principles can lead students' observations to a fuller understanding of the common ancestry of all trees?

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SCIENCE STORY

Studying Street Trees

I am entering an all-girls urban middle school and upon entering the ninth floor of the building I and the arriving students are warmly greeted by Wanda, the security person engaged to check the students in. Ms. Ellis teaches science to sixth- and seventh-grade students and I am a guest in her first period sixth-grade science class. Walking into her brightly lit science room, there are artifacts from trees everywhere! The back table has leaf presses, seeds, pods, samaras, acorns, dried leaves, and preserved pressed leaves. On each of the six lab tables is a plate of several acorns, all of which come from the same tree. Prior to the lesson, Ms. Ellis explains that she is hoping the students will be curious to locate what they are exploring inside the classroom when they go outside later this week. On the board:

> The Aim: How can careful observations assist us in identifying something?
>
> Do Now: Are there any trees outside the front of the school? Can you describe them? Do you think anyone takes care of the trees here in the city? Do you think anyone should?

I love this room—the students eagerly walk in and notice the acorn piles on the center of the tables. They take their seats and respond in their notebooks to the "Do Now."

Ms. Ellis begins by saying "Before we can go outside with our iPods and Leafsnap apps, we have a lot to explore in class." She asks, "Did anyone go anywhere this weekend where they noticed lots of trees?" Students talked about trees near relatives' houses, trees in the large local park, trees near their church. . . . One student offered that she started noticing trees because they were talking about them in class. There are twenty-five girls in total, all new to the school, several new to science. Girls talk about the trees outside school in vague terms, so Ms. Ellis assigns homework: "How many trees are out front on the street where our school is located? This side of the street? Are they all the same kind? Do you think they look healthy?"

They then discuss tree caretakers in the local park—those who prune and even water the trees. Ms. Ellis remarks that that would be a cool job! They then discuss the acorns on the table and reach consensus that they contain seeds that could grow into a new tree. She instructs the students to select one acorn from the center piles on their tables and record a description of their acorns with great detail. After a few minutes, the girls return their acorns to the center pile and one student mixes them around. They are then instructed to find their acorns. They have ten seconds. Ms. Ellis asks, "How do you know it's your acorn?"

Responses included "Mine was very tiny with a pointy cap," "My acorn had a round dark spot on it," and "The top of my acorn has a piece of stem attached to it."

Students trade notebooks with another student and, based on their acorn description, the student has to find her partner's acorn. Ms. Ellis asks how many found their neighbor's acorn based on the written description; she then solicited good and bad descriptions. She asks, "Do you think these acorns all came from the same kind of tree? Why? Why not?" The students conclude that they came from the same kind of tree because they look very similar.

After the acorns are collected, Ms. Ellis distributes new materials to each table; this time they are artifacts from trees. However, each table receives a different assortment. These include samaras, dried pods, preserved pressed leaves, hairy seeds in a shell, horse chestnut spiky balls, and different simple and compound leaves that were dried. Students use dry erase markers to write descriptions of these artifacts on their desktops (which are dry erase boards). They are asked to be detailed, and they describe the items by size, color, and things they already know. Ms. Ellis says, "Some of you are using magnifying lenses to find tiny details. This is what scientists do; they also compare objects to what they

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already know." The girls then rotate tables and add descriptions to those already written there. They do this twice and have exposure to three sets of materials. Ms. Ellis then asks them to draw a square in the center of the table and write the responses to this question: What do all the things on your desks have in common? Girls write things like "They were once alive," "They come from plants or trees. . . . "

The students erase their desks as the period closes, and Ms. Ellis will follow up with them the following day. They are scheduled to go outside in two days.

The Next Day: Preparing to Use the Leafsnap App

Upon entering Ms. Ellis's classroom the next day, the SMART Board is on with the following:

> Do Now: How do we use the Leafsnap app?
>
> Do Now: We are going to be using iPods in class today. Working with a partner at your table, come up with three important rules we should follow when using the iPods.

With the class the following emerges:

1. Use caution: Don't damage the screen.
2. Use only for Leafsnap—do not download other apps or play with the iPods.
3. Share the iPod with your partner at all times.
4. Do not take the iPods home; that is, don't steal!
5. Do not delete the Leafsnap app.
6. No food or drink near the iPods.

Students initial their agreement next to the number of their iPod.

Students select one each from four piles of leaves at the front of the room. Ms. Ellis tells the stories of where she found them—waiting for the train near her house, walking across the local park this morning, and on the corner of the street the school is on . . . the girls grin.

Students are instructed to follow the directions that are indicated on the SMART Board:

> Take a picture of one of the leaves and write the name of the tree on the erasable desk surface. Students photograph their leaves and make choices for the tree name based on the generated list.

They label their leaves on their tables: American Elm or Slippery Elm; Ginkgo Biloba; Scarlet Oak or Pin Oak; Sugar Maple or Norway Maple.

Ms. Ellis asks: "How sure are you that the trees match the leaves? How did you make your choice?"

On the SMART Board it states:

> Compare your choice with others at your table—do they match? How confident are YOU that your Leafsnap choice is the correct one?

Starting with the leaf that looks like a fan, everyone had Ginkgo Biloba. Ms. Ellis asks, "What does this tell us about this tree?" They conclude that it is unique, and she tells them where she found the leaves.

For the Maple leaf, some students had Norway Maple, whereas most had Sugar Maple. She then displays the Leafsnap image on the SMART Board, demonstrates how to label leaves in their collection, and interrogates the duality. They conclude that we need more evidence to say for sure the name of the tree—we need to stand in front of the tree!

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> ***Plant blindness:*** *the inability to see or notice the plants in one's own environment—leading to: (a) the inability to recognize the importance of plants in the biosphere, and in human affairs; (b) the inability to appreciate the aesthetic and unique biological features of the life forms belonging to the Plant Kingdom; and (c) the misguided, anthropocentric ranking of plants as inferior to animals, leading to the erroneous conclusion that they are unworthy of human consideration.* (Wandersee & Schussler, 1998)

They repeated the procedure with the American Elm leaf and the Oak leaf, and then the students were asked: What could you do to confirm that our tree choices were correct? She distributes the first worksheet and invites the students to find a leaf and, using the guide, identify it for homework. The students are engaged and enthusiastic and loving the iPods!

Time to Go Outside

The students are aware that they will take a picture of a leaf from a local tree by gently separating the leaf from the stem and placing it on a white piece of paper. The camera in the Leafsnap app takes the picture and poses several choices for the name of the tree (Figure 4.1). Walking outside with the students and their teacher, I was struck by how excited the girls were to examine the leaves from the local trees. They had already discussed "plant blindness," a phenomenon where so many people (and most students) take no notice of plants, including trees, and now they are venturing outside to specifically study the characteristics and names of the trees. This purposeful observation is fun to watch. After the girls "leafsnap" their tree sample, they decide which one it is and then examine how the leaves are arranged on the stem (opposite one another or alternate); what the bark is like; and what, if anything, other than the leaves is attached to the branches. The students notice acorns from the oak trees and samaras from the maple trees, but they

FIGURE 4.1 Images from the Leafsnap App

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are surprised to find other structures that we call pods or legumes. They are beginning to learn about local biodiversity. When they arrive at a decision about which tree it is, they are asked:

- Does your evidence support your Leafsnap hypothesis? Explain your reasoning. As with any good explanation, make sure that you cite specific evidence!
- If your Leafsnap hypothesis was NOT supported from your evidence, what tree do you think you actually found?
- Examine the other choices and explain why one of the others is a better choice OR explain why you don't think any of the choices actually are supported. Again, make sure that you include necessary evidence!

Students are directed to scientifically observe trees instead of casually observing them or noticing them. The focus here is on using a comparative method, as do scientists, to contrast the features of, in this case, the trees, with the information provided by the handheld technology and the other trees on the block. The hope is that the students will begin scientifically observing the trees like expert biologists. Students spend several days exploring local trees and collecting data about them, recording those data in their notebooks in a format similar to Figure 4.2. They start thinking and talking about their tree observations, and this type of observing in the disciplinary framework of relatedness leads them to understand the centrality of the fruit of the tree (i.e., acorn, samara, legume) and to begin to group trees based on their specific characteristics. The goal is to foster urban middle school student interest in and learning of local biodiversity and the patterns of evolution. This beginning, using the Leafsnap app, is an important step to encourage scientific observation. The context is learning about the common ancestry of

1. Find your target tree! (This will be assigned to your pair.)
2. Remove a leaf from the tree (or if it is very tall, look on the ground and see if there is a leaf from that tree nearby).
3. Use Leafsnap to develop a hypothesis about what type of tree it is. Your Leafsnap hypothesis is the **first** tree that comes up on your list.

   Leafsnap Hypothesis: Our tree is a _____.

4. Provide evidence to determine if the Leafsnap hypothesis is supported. To do this, use the "Name that Characteristic" worksheet to help you identify other characteristics of your tree.
5. Compare **all** tree characteristics to those pictures that are included with Leafsnap.
6. List the characteristics and how they compare in the space below. **You need to include at least four characteristics, such as shape of leaf, back of leaf, edge of leaf, bark of tree, arrangement of leaves on branch, fruits/flowers, and so on.** Make sure that you use proper descriptive language, as provided on the worksheet!

Characteristic	How it is shown in Leafsnap	How it appears on my tree	Check for Leafsnap Tree Match (√)

FIGURE 4.2 A guide for students to record their observations

Professional Resource Download

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the trees by studying their identifying characteristics. Shared fruit, leaf, and flower structure is evidence of common descent.

The Teaching Ideas behind This Story

- Notice how Ms. Ellis engages the students with tree-related objects from nature before exploring *Leafsnap and going outside.*
- The contract that the students initialed when taking the iPods to be used in class and outside became a class activity in which all the students had "buy-in."
- The students worked in pairs, making it possible for them to help each other as they used the app to capture photos of the leaves and come up with their hypothesis.
- The outdoors experience extended into the classroom with data recording and sharing.

The Science Ideas behind This Story

- Eighty percent of Americans live in cities or suburbs and are very disconnected from their environment where they are often unknowingly surrounded by many forms of life. Street trees provide an opportunity to engage students in biodiversity.
- The tree characteristics used to determine relatedness and common ancestry are leaf, fruit, and flower structure. Shared fruit, leaf, and flower structure is evidence of common descent.
- Traits are a reflection of ancestry.
- Different plant groups have similar and different traits that are adaptations that help them to survive and reproduce.
- For example, all plants have green leaves for photosynthesis; all flowering trees have fruits to disperse their seed; fruits may take different form in different species groups.
- Plants have different forms for the same function. These forms are shaped by an organism's ancestry. For example, all flowering trees have fruits for seed dispersal, but some plants use samaras (maples and ashes), some use acorns (oaks), and some use pods. All trees have leaves that perform photosynthesis, but leaf form in the same environment varies by species group.
- Traits cannot change based simply on need—there is a limit to how much fruits and leaves can change. For example, animal-dispersed acorns are too heavy to transform into wind-dispersed winged seeds.

Connections to the Next Generation Science Standards

- **NGSS DCI: MS-LS4.A: Evidence of Common Ancestry and Diversity:** Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent.
- **NGSS SEPs:** Students were engaged in *analyzing and interpreting data*, *constructing explanations*, and *engaging in argument from evidence*. They *obtained, evaluated, and communicated information.*
- **NGSS CCs:** Students recognized *patterns* and *structure and function* when examining the characteristics of trees.

4-5 Scientific Data as Evidence

The following Science Story describes seventh-grade students' experiences as they explore scientific data related to their environment. Along the way, as you will see, the students caught a glimpse into how scientists work on issues affecting changes to ecosystems.

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SCIENCE STORY

Ecology Disrupted

Seventh-grade students in an urban area near Baltimore, Maryland, are learning about ecosystems while exploring how scientists work. Their teacher, Ms. Kane, has introduced students to what is meant by an ecosystem. She talks to the students about the snowfall amounts that accumulated in their area the previous winter. The students recall the record-breaking winter in Maryland, where over 80 inches of snow fell in a region ill-equipped to handle it. She asks students to think about what substances were used to help melt the snow and ice. The students recall road salt and sand as a way to help drivers get around. She asks students to think about how these abiotic factors could affect our ecosystem.

Prior knowledge: *These seventh-grade students already understand that an* ***ecosystem*** *is a natural unit, a defined space in which living things (biotic factors) function together with nonliving or abiotic factors in a specific environment. Abiotic factors include all the nonliving chemical or physical factors in an environment, from the quality of the gases in the atmosphere to the types of buildings, roads, and soil that are present.*

The specific abiotic factors that Ms. Kane wants to explore with her seventh graders are the roads in the Eastern United States and the road salt that is used on them in instances of heavy snow and ice. The students are shown satellite images of North America with red lines indicating the roads. Students see that parts of this area are almost totally covered with roads, whereas some parts seem to have few roads. Next, Ms. Kane shows a map image of the Baltimore area and explains that scientists are exploring the area's water supply. Scientists, she says, are exploring the following question:

How do snowy and icy roads put the Baltimore area's water supply at risk?

The students now receive a set of six photographs, one set for each group of four students (Photo 4.1). The photos depict a snowy urban scene, roads with white residue on them, a salt-spreading truck on snowy roads, and rivers and streams near bridges and elevated roadways. The students are asked to make observations about the photos and to suggest how snowy and icy roads may place the water supply in their area at risk. The photos constitute a data set, and Ms. Kane wants the students to relate the data to the study question. Each group of four students arrives at some form of the following hypothesis:

Salt spreaders add salt to icy or snowy roads, and when the snow melts, the salty melted water washes off the roads to rivers and streams and sewers.

One group goes as far as to say that fish could be harmed by the salty residue.

My thinking: *I am impressed by how well the students work on this challenge. At first, they are unsure why the photo of the salt-spreading truck is in the data set, but then they see the connection. I think, "Would they have thought that salting the roads could harm the environment before this unit?" What do you think?*

For homework, students are given a fact sheet about salt water, and they are asked why people don't drink salty water (Table 4.1).

My thinking: *The fact sheet and accompanying questions help to scaffold the students' thinking. Now that they have identified salt as the abiotic factor in this ecosystem, they can consider its effects on living things (biotic factors) by exploring these data.*

When students enter Ms. Kane's science class the following day, there are stations with table salt in beakers, lightweight paper cups, and digital scales. At each station, students are asked to weigh a specific amount of salt, ranging from 50 mg to 750 mg. Students are surprised by how small the amounts are; using the numbers without relating them to real quantities is often misleading. After students make the measurements, students are asked to mix the salt into liter bottles of water. After tasting the waters with varying salinities, they understand that even small quantities of salt in a liter of water can affect the quality of the water.

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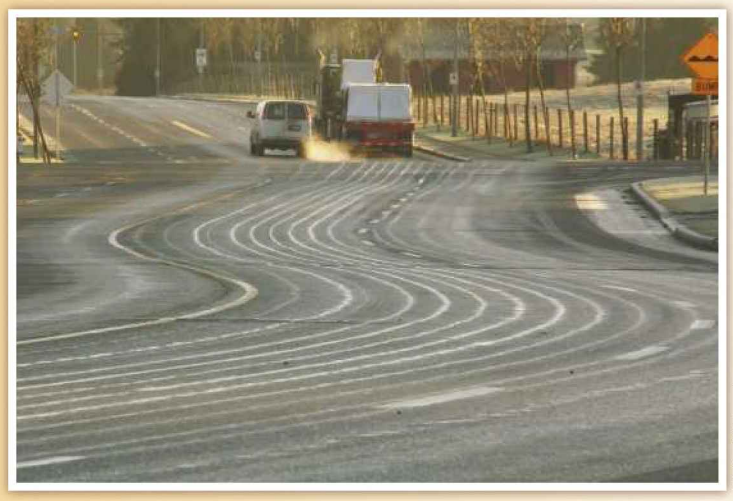

Modfos/Thinkstock

PHOTO 4.1 Photos such as these are used as the data set in Ms. Kane's classroom.

A final station has two halves of an eggplant exposed. On one half, Ms. Kane has liberally covered the surface with table salt. After 30 minutes, the eggplant half covered with table salt has water pooling at the surface, demonstrating how salt draws water out from organic matter, dehydrating it. Ms. Kane then explains that scientists have been checking the level of salt in nearby streams and rivers and in the drinking-water supply in the Baltimore area since the 1970s, not long after salt-spreader trucks came into heavy use in the area. She shares with the students the numerical data shown in Table 4.2. She asks, "Why do you suppose scientists began to do this water testing soon after salt-spreading trucks were sent out on snowy and icy roads?"

One student, Mia, answers, "Maybe they were concerned about where all the salt would wind up?"

At this point, Ms. Kane shows a brief video of Dr. Sujay Kaushal, the author of the scientific paper from which the data are taken. In this video, Dr. Kaushal recalls how he and his sister used to walk along the banks of streams in rural Tennessee. He remarks about all the articles of pollution you could see on the banks of these streams and wonders about all the things that were in the water that you could not see. He says, "the water in the streams and rivers are a reflection of all the bad water quality things we do on land." Students could actually see the crystallized road salt on the side of the streams that he studies around where he currently lives, in Maryland. The students get a feeling now for the motivations of this scientist. Ms. Kane remarks, "Whenever we add something to the local ecosystem that does not *naturally* belong there, we want to learn how the system is affected."

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TABLE 4.1 The Fact Sheet about Freshwater and Salt Water Given to Ms. Kane's Students

How much salt does salt water have?	■ Water with salt levels greater than 250–400 milligrams per liter (mg/L) will taste salty. ■ Water with salt levels under 1,000 mg/L is considered to be freshwater (not salty). ■ Water with salt levels between 1,000 mg/L and 3,000 mg/L is considered to be slightly salty. ■ Water with salt levels between 10,000 mg/L and 35,000 mg/L is considered to be very salty. ■ The salt level in the open ocean is approximately 35,000 mg/L.
How does salt affect freshwater animals and plants?	■ Some freshwater animals and plants die when salt levels reach 226 mg/L for extended periods of time. Smaller animals that are the basis of the food web are the most sensitive to high salt levels. ■ Some frogs die when salt levels exceed 400 mg/L. ■ Freshwater fish like rainbow trout die when salt levels reach 1,000 mg/L for an extended time. ■ Salt levels as low as 68 mg/L negatively affect roadside plants, such as pine trees. ■ Large animals like elk, bighorn sheep, and seed-eating birds have all died from eating road salt. ■ The EPA (Environmental Protection Agency) drinking standard for humans specifies a salt level no higher than 250 mg/L.
Snowmelt runoff	■ Snowmelt doesn't just sit. It moves. It follows one rule—GRAVITY! Water always flows down. ■ When water flows over hard surfaces like roads, it carries whatever is loose on the surface with it, such as salt and litter. ■ Water flows into storm drains, which empty into streams. Streams flow into rivers and lakes. All rivers eventually flow to the lowest point—the ocean. ■ Some water is collected in reservoirs for people to drink. The process of storing water in reservoirs helps to clean the water naturally. Sometimes water is also filtered and disinfected before it is sent in pipes to the tap. But salt is not filtered out of the water!

Shawn offers, "Just like dumping waste water from factories into the river." Ms. Kane agrees, and suggests that the students can think about other examples of abiotic factors affecting ecosystems.

Now the students begin to examine the data in Table 4.2 in detail. They are also given data sheets that reflect the salinity levels in the *urban*, *rural*, and *suburban* areas for the last seven years. In each group of four, students select a data sheet to graph, making sure that the scales on each graph are the same. The students understand that one way the scientists make decisions about their data is by representing those data in graphs. They see that in urban areas the water is much saltier than in the area's suburban or forested

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TABLE 4.2 Average Salt Levels in Baltimore-Area Streams (mg/L)

	1999	2000	2001	2002	2003	2004	2005
Forested area	2.60	2.54	2.66	2.39	2.69	2.77	2.66
Suburban area	243.79	62.43	68.81	89.08	96.74	115.70	181.23
Urban area	332.22	344.98	235.47	256.34	358.47	454.90	777.73

Source: Institute of Ecosystem Studies, Baltimore Ecosystem Study, www.beslter.org.

regions. The students reason that the more prevalent the roads, the greater the need for salting them on snowy and icy days. They also reason that in 2009, when the Baltimore area had record snowfall, the salt content of the water must have increased rapidly in both urban and suburban settings. They conclude that the data support their hypothesis that salty melted snow washes off the roads and eventually reaches the local streams. Ms. Kane shares the story of the road salt making television news the previous winter. The newscaster reported that "scientists are concerned about the amount of salt we used on the road this winter!" Knowing that Ms. Kane analyzes scientific road salt data, her family was excited to see it on television and called her when they heard the report. This unit is referred to as "Ecology Disrupted" since the abiotic factor introduced to the system disrupts the chemical balance in freshwater streams and rivers.

After the students complete their graphs and study the data that Dr. Kaushal had collected and analyzed, Ms. Kane asks the students which areas were most affected by the salting: urban, suburban, or forested areas? Many students immediately say "urban," since the salinity levels were highest there; however, a large number of students feel that suburban streams also had high salinities, and since there are not as many people in the suburbs as there are in the city, perhaps the suburban streams were most affected when compared to the population. Then the students reach at least one surprising conclusion: Although rural areas seem to be so much less affected by road salting than urban areas, if you analyze the population in relation to the salinity, you find that rural areas have an unwarranted amount of road salting for the level of the population. When Ms. Kane asks what living things were most affected, the students focus on the plight of the fish in local freshwater streams.

Ms. Kane asks the students to brainstorm possible solutions to the crisis of adding massive amounts of road salt to the ecosystem during snowy and icy winters. Students work in groups and brainstorm the question and come up with suggestions that range from using public transportation to manufacturing less harmful materials to help melt snow to finding ways for tires to be coated with substances that melt the snow. Although the ideas sometimes sound extravagant, any idea is better than no idea! I am impressed that brainstorming solutions is part of the science lesson.

As a culminating activity, the students use the Web to access the *Science Bulletins* from the American Museum of Natural History on which these data were based. They also examine a *Science Bulletin* focusing on the urban heat island effect. Although this study was done in the city of Atlanta, these city students could relate to how much hotter it is in the city than in areas that have less brick, mortar, and asphalt. The abiotic factors in this disrupted ecosystem were the construction materials used and the design of the buildings. When Ms. Kane asks for possible solutions, one student mentions the roof gardens that were being developed all over the city. The plants would hold on to less heat energy than the artificial building materials.

The Teaching Ideas behind This Story

- Connecting real scientific data to a locally relevant problem engages the students in authentic science experiences—in this case, in environmental science.
- Ms. Kane made connections to the enormous amounts of snowfall the students experienced the previous winter in their own neighborhood.

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- Gathering the data often requires the assistance of the Internet; in this story Ms. Kane used the Web to access two of the *Science Bulletins* from the American Museum of Natural History, "Winter Roads Make Salty Streams" (2006) and "Urban Heat Island Effect" (2004).
- *Science Bulletins* are video and slide programs from the American Museum of Natural History that bring you the latest developments in the fields of astrophysics, earth science, biodiversity, and human biology and evolution through documentary feature stories about scientists in the field and regular brief research updates using scientific visualizations and imagery. Ms. Kane's lessons and the video of Dr. Kaushal, based on these bulletins, were made possible by funding from National Science Foundation Grant #0733269 (2007).
- To help students connect the weather conditions to the addition of salt to the ecosystem, photos were used, showing salt residue on the sides of the roads as well as a salt-spreading truck. Students were asked to make observations of the photos and to draw inferences from those observations.
- To give meaning to the abstract numbers on the data sheet, Ms. Kane had the students work with digital scales, table salt, and paper cups. The process of creating their own salt water solutions concretized the lesson for the students.
- This story illustrates one of the National Educational Technology Standards (NETS) for Teachers (International Society for Technology in Education, 2008): "Teachers design and develop digital-age learning experiences." In this case, the teacher drew data, photos, and a satellite map from the Web source and at the end of the lesson had students themselves access the source to see the material in its original context.
- Students were surprised that a seemingly harmless action—accelerating the melting of snow and ice by salting the roads—could potentially harm the environment. The concept of unintended consequences of human intervention in the ecosystem is a key teaching idea behind this story.

The Science Ideas behind This Story

- According to the *Science Bulletin* on which this lesson was based, more than four million kilometers of paved roads crisscross the United States, with more built daily. In winter, salt is regularly applied to melt ice on roads in many areas of the Northeast and Midwest. But road salt runoff drains into streams and drinking water.
- Scientists have been testing freshwater in three regions of the Northeast for thirty years. The salt buildup has made some urban, suburban, and rural streams 25 percent as salty as seawater. If excessive salting and road-building continue in the Northeast, by 2100 the area's freshwater may be toxic to wildlife and unfit to drink (Kaushal et al., 2005).
- Salt lowers the freezing and melting point of water. Ice forms when the temperature of water reaches 32 degrees Fahrenheit (0 degrees Celsius). When you add salt that temperature drops; on a roadway, this means that if you sprinkle salt on the ice, you can melt it.
- The salt **dissolves** into the liquid water in the ice and lowers its freezing point.

Connections to the Next Generation Science Standards

- **NGSS DCIs:**
  - **MS-PS1.A: Structure and Properties of Matter:** Substances are made from different types of atoms, which combine with one another in various ways. . . . In a liquid, the molecules are constantly in contact with others.
  - **MS-LS2.A: Interdependent Relationships in Ecosystems:** Organisms are dependent on their environmental interactions both with other living things and with nonliving factors. In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for access to these limited resources, constraining their growth and reproduction.

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- **NGSS SEPs:** Students engaged in *analyzing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions,* and *engaging in argument from evidence.*
- **NGSS CCs:** Students examined *patterns* in the urban, suburban, and forested data; they looked at *cause and effect* in their data; and examined condition of *stability and change* in the evolution of these natural systems.

Exploring Further

In order for you to implement this experience in your own classroom, you may want to consider answers to the following:

- In light of the unintended consequence of salting the roads in urban Baltimore County, what suggestions, other than using salt, could be made to local officials?
- The American Museum of Natural History offers many *Science Bulletins* related to contemporary issues in environments around the world. For example, "Urban Heat Island Effect" examines the temperatures in and around Atlanta, Georgia. How much hotter can urban environments get than rural areas? What abiotic factor contributes to this drastic rise in temperature? Do you have any suggestions to reduce the urban heat island effect?

4-6 Field Trips

ecosystem
A natural space in which all the living things (biotic factors) function together with all of the nonliving things (abiotic factors) in a specific environment.

dissolve
When solid particles (such as salt) are broken down into invisible particles when placed in a solvent such as water. The solid particles seem to disappear because they are present in molecular or ionic form.

As we saw from the previous story, science can connect to the world outside the classroom simply by taking the students outside, whether for a short stroll around the school grounds or a more extensive field trip. As Richard Louv remarks, "In the space of a century, the American experience of nature has gone from direct utilitarianism to romantic attachment to electronic detachment" (2008, p. 17).

I was visiting an elementary school in the Northeast one winter morning when a teacher I knew said, "Hi. The class and I are going to visit the Hall of Science today." This is a fine hands-on museum not far from the elementary school. I responded, "Great! How come you are going now?" She said that she had planned the trip weeks ago and thought that, at this time of year, it would be good to get the students out of the classroom.

It struck me that something was lacking in her definition of the trip's purpose. Certainly it is always a treat, if your school has the resources, to take students on class trips, but science field trips can be much more meaningful if they are directly connected to the unit or topic the class is studying. By linking the trips with class study, we reinforce the learning experience—and we demonstrate that science is more than a subject confined to the classroom.

In addition to offering relevant science content, a field trip should provide students with the opportunity to exercise their science process skills. Invite your students to engage in some problem solving outdoors (Photo 4.2). For example, a fourth-grade trip to the seashore might involve taking notes, collecting articles of interest, and perhaps using a ball or two to explore the actions of the ocean waves. The teacher could engage students in recording their observations, drawing what they see, and solving one or more problems that they have previously brainstormed in class. On a similar field trip, an eighth-grade class might collect beach samples in resealable plastic bags to be examined later under a microscope. The students might also collect some ocean water to determine density, turbidity, and salinity. Allowing the ocean water to evaporate is another exciting activity; what remains behind will include the various dissolved and undissolved substances contained in ocean water.

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PHOTO 4.2 These students are not merely collecting plants on a field trip. They are exploring their own questions about the local environment, and in this way the excursion becomes meaningful for them.

Whenever possible, share your rationale for venturing outdoors with the students. Involve them in planning both the excursion itself and the questions it will seek to answer. Ask them, for instance:

- Why do you think we are going there?
- What shall we bring?
- What do you wonder about?

Your students will have good ideas concerning the trip as well as their own stories to tell about related experiences.

4-6a Tips for Outdoor Science Experiences

- Careful planning is essential. For field trips, letters of consent are usually required from parents or guardians, and students should be guided to dress properly for the chosen site.
- Remember to prepare the materials you need to take so students can collect samples and record information. Resealable plastic bags, plastic collecting cups, student science notebooks and pencils, and magnifying lenses always come in handy.
- Students should understand the reason for the outdoor trip and have some ideas about the problem they are exploring.
- The trip should lead to further investigations or research in class, as illustrated by the following science notebook entry by a young student named Ana:

  > *I went on a field trip with my class to the Duck Pond. We were looking for something new we had never seen before. When we came back to the room we all guessed what it was. Based on our past experience we all said it was either a beehive or a wasp's nest. We tried different experiments to find out what it was. After researching it we identified it as a praying mantis home.*

- Adult supervision is required. Depending on the type of excursion and the number of students you are taking, you may need to ask other adults to accompany you. These adults should also participate in the planning for the trip, if possible.

In the following science stories, we will see some examples of science learning experiences both in and outside of the classroom.

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SCIENCE STORY

Making Connections, Inside and Outside the Classroom

An Urban Park and the Story in the Rocks

The students in an urban fifth-grade class have been studying rocks and how they form. One city block from the school is a large, beautiful park. Mr. Wallace, the science teacher at this school, takes the fifth-grade classes, one at a time, on a field trip to explore the rock outcroppings in the park. He selects one large outcropping and encourages the students to make detailed observations and drawings.

Before the field trip, Mr. Wallace informs the students that they will need their science notebooks, and he distributes to each student a diagram that looks like a blank circle with grid lines running across and down so that there are sixteen cells within the circle. Mr. Wallace displays two large hula hoops that have been fitted with strings, creating the same sixteen-cell grid. He is also carrying compasses. He explains to the class that their goal for this field trip is to observe the rock outcropping in the way a geologist would. "We are looking for cracks, lines, and scratches and areas where the rocks appear to have been folded over." He wants them to create scale drawings of what they see, using the hula-hoop grids as guides. They will lay a hula hoop over the rock surface and then draw on their own grids what they see in each cell of the hula-hoop grid.

During the short walk to the outcropping, which slopes gently on a hill, Mr. Wallace explains that most of what we learn about the earth's history and structure comes from observations of rocks. "When you are finished making your observations, I will collect your notebooks and see what I can learn from your observations and from what you have drawn."

He asks the students to comment on what they initially notice. The students observe shiny minerals in the rock and conclude that these are mica chips and that this rock is a metamorphic rock. "When we can see micas large enough to reflect light, it is a good bet that the rock is metamorphic," says Mr. Wallace. It is clear that these students have learned the three rock types (igneous, sedimentary, and metamorphic) and their properties. He indicates an area where the rocks appear to have been bent around and curled, and he explains that we can conclude that something must have happened a long time ago to account for this appearance. He places one hoop over a part of the rock's surface and another hoop over another section, a few meters away. The students begin to draw the marks and lines they see on the rock in the corresponding cells on their paper grids. Mr. Wallace says, "Notice the cracks and the grooves. They tell us a story." These are features that interest geologists, he points out. He has centimeter tapes, and the students measure the distances between the grooves. Mr. Wallace explains that these are clues to what lies below. "Clearly the rocks formed and then the cracks. The big question is when did these cracks form relative to when the rocks formed?" The students use a compass to orient their drawings to the cardinal directions (north, east, south, and west) and to show which way the cracks are going.

Mr. Wallace then asks the students how hard they think these rocks are. He reminds them that in geology the term *hardness* refers to what material can scratch the rock; he takes out a penny for the students to use in testing. Can a penny scratch this rock?

The students are busy measuring; drawing, describing, and I get the sense that they will never again see these rocks as just a nondescript grey outcropping. They are now a clue to the history of the region. Mr. Wallace returns to the idea of the order of events. First there were rocks, he suggests, then cracks, then scratches; the cracks go across the folds, so that means the folds came before the cracks.

The students eventually surmise that the cracks line up with regional fault lines. Although this is a tiny piece of the story, the students are getting the idea that geologists make independent observations of all the rock outcroppings in the area, and then their combined data begin to tell the story of the region's history.

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The Osage

When a fourth-grade student in southern New York State brings an interesting-looking fruit to class, neither the teacher nor the other students have ever seen anything like it. "This fell from a tree near my house, and I don't know what it is," the student says. "Can we put it in our science center?"

"That's a very good idea," remarks the teacher. "What question can we put on our index card?"

"Let's ask, 'What do you think this is?'" the student replies.

Over the next few days, the class becomes intrigued by the strange-looking fruit. The students write in their science notebooks the qualities they notice about it. It is green, they observe, and has thick, bumpy skin like an orange. It also smells a little like an orange. They wonder why the skin is so thick.

After recording their observations and questions, the students explore the school library and finally ask for assistance. With the librarian's help, they find a picture and description of the fruit in a resource book. It is an osage, they learn. But their curiosity has been piqued, and they don't stop there.

Now they read about where the tree grows, how it got its name, and much more. They learn that an osage is the fruit of the osage orange tree, which belongs to the mulberry family of trees. It was originally found in Texas, Oklahoma, and Arkansas and named after the Osage Indians of that region. It is an inedible fruit, and its tree has a short trunk and crooked branches. It is planted around the United States for hedges and ornamental purposes.

For the rest of the school year, everyone in that fourth-grade class looks for osage orange trees.

Two Seashores

With collection bags in hand, students in a sixth-grade science class on Long Island visit the south shore, the ocean side of the island. The sand forms smooth dunes here, and its fine grains glisten in the autumn sun. The students make drawings of the sparse plant life on the beach, and they study the shells that have washed up. They collect various artifacts to take back to their classroom. Back in the school, using reference books and websites, they identify the marine invertebrates whose shells they have found.

On another trip, they visit the north side of the island, where the bay gently brushes against a craggy shore. They notice how very rocky and pebbly it is. Encouraged by their teacher, the students begin to wonder why this north shore looks so different from the south. They make more drawings and return with sand and rock samples to compare with the samples from the south shore.

In the next weeks, using books, tablets, and the Internet, they learn about the effects of the ocean and inlet bays on landforms. They make inferences, come up with their own ideas, and research areas of personal interest. The students' comparison of the two shores yields some important science concepts.

Investigating a Natural Disaster

A major earthquake strikes California. News of the sudden destruction floods the television and print media nationwide. In Texas the next day, one fifth-grade teacher begins doing "earthquake science," despite the fact that it is not listed in the formal fifth-grade curriculum.

The students clip newspaper stories on the disaster and hang them around the room. Prompted by the teacher, they write down their earthquake questions and research them in library books and on websites. In the science center, some students make clay models of the earth's crust and use plastic knives to cut lines in the clay to represent faults. Others use layer cakes in cake pans that are precut before the cakes are baked. (When you bake a layer cake in a pan that has been cut slightly on the bottom, the layer comes out sporting a large crack, which resembles a fault in the earth's crust.) Using these models, the students learn that an earthquake is a sudden slippage of rock that sends enormous shock waves through the earth.

The students also write stories about the earthquake and take collections for the earthquake victims. Besides increasing their understanding of earthquakes in particular, these explorations help make the students aware of the impact of natural events on human lives.

Coconuts Outside the Door

Outside the door of his apartment complex in south Florida, Mr. Appleton, a seventh-grade teacher at the local middle school, finds a coconut that apparently has fallen from one of many palm trees that line the

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Exploring a Coastal Plain

As teachers, we often have fascinating natural phenomena right under our noses, but familiarity tends to breed indifference. The first step in bringing the local environment alive for our students is to pay attention to it ourselves.

In a small coastal fishing community in Maine, ten elementary school teachers accompanied me to a part of their coastline, an inlet where granitic mounds of rock dotted the landscape. This place was just down the road from the elementary school, and the teachers were discussing how to use their local environment as a living laboratory for their students. For me, it was a mysterious and interesting site, but for these local teachers it seemed quite ordinary because they had seen it countless times before. "What do you notice?" I asked them. "Tell me everything, anything." Thus prodded, they began to observe more than they had suspected they would. For example, it was low tide, and my companions pointed out that all the mounds of rock had water marks, which indicated the point to which high tide had risen that day. *Tides*, these teachers knew, are the rise and fall of the oceans caused mainly by the moon's gravitational pull on the earth. The waters on the side of the earth facing the moon bulge out toward the moon's gravitational pull, creating a **high tide**. The other side of the earth, facing away from the moon, has high tide simultaneously because the moon's gravitational pull has pulled on the solid earth as well, leaving the waters bulging on the opposite side of the earth. Meanwhile, as the waters bulge on two sides of the earth, the waters on the other two sides flatten, causing lower levels of water, or **low tides**. Because the earth rotates on its axis once every twenty-four hours, the tide rises for about six hours at a particular point, then falls for about six hours.

The teachers knew all this, but it hadn't occurred to them that they could use the inlet down the road from their school as a place for their students to investigate the concepts of tides, gravitation, and the movements of the earth and moon.

As we stood there, we noticed that some untidy seagulls had left the shells from the mussels they had eaten atop a large rock, which had served as the gulls' dining table. That observation sparked a discussion about food chains.

One teacher picked up a dried scallop shell in which a spider had spun its web. Talking about it, we brought up ideas about animal habitats, ecosystems, and more.

These teachers were so impressed with the natural phenomena under their noses that they took their students to the inlet the next day to collect materials for science center interest.

street opposite the beach. He looks up, and under the spreading arms of the palm tree's large leaf stalks he sees bunches of coconuts, some already brown, that appear ready to detach themselves and fall.

Bringing the coconut into his science class, Mr. Appleton shows it to the students. "Look what I found outside my door," he says. "I was wondering what you think. Is this living or nonliving?" The students are amused; they know they are starting life science in seventh grade, but yesterday they looked at pond water and explored single-celled organisms with their microscopes. "What does this have to do with paramecium?" asks Dean.

"What makes you ask that question?" responds Mr. Appleton.

"Well," Dean says, "I thought we were doing life science now."

"We are," says Mr. Appleton, "so we are wondering: Is this coconut living or nonliving?"

All of the students have seen coconuts before. In their coastal neighborhood in tropical Florida, palm trees are everywhere. The students offer various ideas about the coconut. Most of them are reluctant to say it is not living, but they are unable to say why they think it is alive. The consensus in this class is that the coconut *will become* a living palm tree if planted in the ground, but for now it is "dormant." Mr. Appleton asks what they mean by dormant and invites them to do research on the coconut.

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The students then proceed to explore, in research books and on websites, what processes living things perform. As they do so, Mr. Appleton raises more questions about the coconut: "Why do you think it has a hard outer shell?" "What about the texture of the nut inside the shell?" "What purpose does the liquid inside, called the milk, serve?" "Do you think the coconut would sink or float in water?"

In the days that follow, students come to class with additional data about the coconut. They place the coconut in a large basin and watch it float. Although they have seen coconuts every day, they have never before interrogated their own environment in this way, and they are surprised that some of the trees in their daily life have become the science topic for the class.

The Teaching Ideas behind These Stories

- Science comes alive when you think of it as a way to explore nature in your own backyard. In four of these stories, the students' scientific inquiry was connected directly to where they lived. In the earthquake story, the inquiry was linked to news reports the students had just heard and to their own collections to assist the victims.
- We can say that these students followed a "both/and" curriculum (McIntosh, 1983). That is, they pursued both the prescribed, formal curriculum of the school and their own informal, self-constructed, experientially grounded curriculum. In effect, an informal curriculum constructs a new textbook—the textbook of our daily lives. ("Making textbooks of our lives" is a phrase first used by Emily Style, codirector of the National SEED [Seeking Educational Equity and Diversity] Project on inclusive curriculum, based at the Wellesley College Center for Research on Women in Wellesley, Massachusetts.)
- Connecting science to students' own lives—in a way that encourages them to explore their own questions—both engages them in using science process skills and validates their sense of themselves as scientific thinkers. This is particularly important for students who might be discouraged or marginalized by traditional science teaching.
- Since classroom science centers should reflect the lives of the students, it makes sense that they vary with the geographic location of the school and the interests and backgrounds of the students. For instance, classrooms in coastal regions may be rich in seashell collections, and inland regions may have rich rock collections. A school in the Southwest may have a marvelous display of different sands and sedimentary rocks on its science table.
- In the coconut story, notice how Mr. Appleton was respectful of Dean's question about whether they were "doing" this subject now. Students see school science as separate from their world and almost resist broadening their point of view. Undaunted, Mr. Appleton continued with his coconut questions and hooked the students on a product of nature that is part of their everyday lives.
- In the rock field trip story, notice how the teacher referred more than once to the way a geologist would look at the rock. He was making the distinction between casual observation and scientific observation.

The Science Ideas behind These Stories

- There are three rock types: igneous, sedimentary, and metamorphic. **Igneous rocks** are formed above or below the earth's surface when magma (below) or lava (above) cools and hardens. The most common igneous rock is granite. **Sedimentary rocks** are formed when sediments, eroded from rocks on the earth's surface, are deposited by rivers into coastal basins or large lakes. Sand, clay, silt, pebbles, and stones are types of sediments that form sedimentary rocks. Sandstone, shale, limestone, and conglomerate are examples of sedimentary rocks. **Metamorphic rocks** are formed from igneous and sedimentary rocks that are pushed below the surface (by shifts in the earth's crust or by lava flows) and subjected to severe pressure and heat. Metamorphic rocks are the hardest of the three rock types; examples are slate, gneiss, and marble. Slate has been metamorphosed (changed) from shale, gneiss from granite, and marble from limestone.
- Osage trees are distinctive because of the fruit's thick, pebbly skin. Like many other plants that originated in dry climates, the osage fruit has evolved an outer coating that protects it from dehydrating. They are not common in southern New York State, where the fourth grader in our story noticed one.

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- Snow forms from water vapor that condenses when the temperature of the air is below freezing. The term *condenses* means that the particles of water vapor come close together, forming droplets of water. When the temperature is below the freezing point, the water vapor condenses into snow crystals rather than into rain. Snow, then, is frozen water vapor. There is a lot of space between snowflakes. The air fills the spaces between the snowflakes, and that is why snow takes up so much more space than the water it turns into when it melts. That is also why the environment seems so quiet after a snowstorm; sounds are absorbed by the air spaces.
- As the students in the Long Island story discovered, seashores have sand particles of different sizes, depending on how the shore was created. On the south shore of Long Island, the constant wave action of the Atlantic Ocean causes rocks to be worn down into tiny sand particles—a process called **weathering**. On the north shore, the water is from a bay, a smaller inland waterway. Here the water action is gentler, the process of weathering is much slower, and hence the rock particles are much larger and coarser than the fine-grained sand on the south shore.
- An **earthquake** is a sudden slippage of rock. Earthquakes occur because the outer layer of the earth (the part we live on), called the *crust*, is made up of huge chunks of rock called *plates*. Rock plates lying next to each other are pressed tightly together. Sometimes the pressure is so great that they need to slip past each other ever so slightly in order to settle in a new position that eases the pressure. This slippage is what we experience as an earthquake. Earthquakes are most common in areas where there are boundaries between the plates or huge cracks in plates. These boundaries and cracks are called **faults**.
- The coconut thrives on sandy shorelines in the tropics. As Mr. Appleton's class discovered, the fruit can float in water, and, in fact, coconuts can travel long distances by floating. When they wash up on a new shore, they can germinate to create new trees. Coconut oil is used in a wide variety of products, including soap, cosmetics, and cooking oils.

Exploring Further

As you consider implementing this type of science experience in your own classroom, consider the answers to the following questions:

- On what kind of landform do you live? For instance, is it a coastal plain, an interior a plain, a plateau, a mountain? How can you investigate what it is called and how the land achieved its current configuration?
- How does nature present itself in your surroundings? Are you near a seashore, a desert, a grassy plain, or a park rich with conifers?
- How many distinct seasons are noticeable in your area?
- In what ways have people changed the natural landscape of your environment?
- What is the local plant and animal life like?
- How can aspects of your local landscape and plant and animal life inform your students' science experiences? How might they be linked to the formal science curriculum?

4-7 Science Centers: Bringing the Outside Inside the Classroom

One way to make science part of the daily life of the classroom is to reserve a table in a center of the room and label it the "science center" or the "science table." In some schools, this area is called the "science center" because it becomes the center of scientific activity in the classroom. Whatever name you choose for it, this area can reflect many possible activities in the life of an elementary school science class.

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PHOTO 4.3 Students examine a model of a human skeleton with their teacher.

high tide
High level of ocean waters, when the waters reach farthest onto land. On the side of the earth facing the moon, high tide occurs because the waters bulge out from the moon's gravitational pull. At the same time, on the opposite side of the earth, there is also a high tide because the moon's gravitational force has pulled the solid earth as well, leaving the waters bulging out on that side.

low tide
Low level of ocean waters that occurs because, as the waters bulge on two sides of the earth, the remaining waters flatten.

igneous rock
Rock formed above or below the earth's surface when magma (below) or lava (above) cools and hardens.

sedimentary rock
Rock formed when sediments, eroded from rocks on the earth's surface, are deposited by rivers into coastal basins or large lakes. These sediments are compacted and become rock through a process called lithification.

metamorphic rock
Rock transformed from igneous and sedimentary rocks that are pushed below the surface (by shifts in the earth's crust or by lava flows) and subjected to severe pressure and heat.

weathering
The wearing away of rocks on the earth by the action of the sun, air, and water.

earthquake
A sudden slippage of rock.

faults
Large cracks or breaks in the earth's crustal plates. Earthquakes are most common in areas where there are major faults.

The materials in your science center need to be clearly displayed in a way that engages the students. Hence signs and materials must be easy to read and in a large font, and directions should be clear and unambiguous. The visual displays should give the students an idea of the topic even if they have limited reading skills. Following the principle of universal design mentioned earlier in this book, make the materials as accessible as possible by all your students. Also be sure to relate each science center topic to overall themes and organizing concepts. Here are a few ideas:

- *Seasonal changes*. The science center can reflect the cycle of ongoing changes in the seasons. For example, an autumn science center might display acorns, pinecones, colorful leaves, chestnuts, and other tree parts that commonly fall to the ground at this time of year in many parts of the country.
- *Materials related to the current science unit*. A science center could reflect the science unit the class is engaged in at the moment (Photo 4.3). For example, a fifth-grade class studying ecosystems might create some small habitats in its science center. A third-grade unit on sound energy might be reflected in the class's science center by student-made instruments.
- *A class nature collection*. A science center can include a potpourri of items from nature that students brought in simply because they found them fascinating. An appropriate title for such a science center might be "The Class Collection from Nature."

4-7a Making the Science Center an Interactive Experience

In many classrooms you can find objects of nature on display in a science center. Unfortunately, if it is just a display area, teachers and students often lose interest in it. These objects merely collect dust and serve no useful purpose.

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To connect science with students' lives, the science center needs an invitation for students to explore, a reason for them to visit. For example, the science center can be a place where students are challenged to consider some questions and then generate their own questions. After visiting the classroom science center, students could be encouraged to write in their science notebooks, reflecting on what they did and what questions the experience raised for them. Students should also generate their own ideas for materials that could be added to the science center as well as questions that could be asked about these new objects.

The following sections offer some clues for turning the science center into an interactive experience that engages students in thinking, in exploring, and in developing their science process skills.

Designing the Science Center with Your Students One way to interest students in the science center is to involve them in designing it and supplying its contents. This participation helps ensure that the informal science curriculum reflects their interests.

In setting up a science center with your students, here are some questions you can ask that will engage them in the process:

- What should we put in our science center?
- What can we *do* there?
- What materials will we need when we explore the objects in the center?
- Can we keep a small class pet there?
- What rules do we need about how and when to use the science center?

Guidelines for Creating a Science Center in Your Classroom

- The classroom science center should reflect the students' interests and, wherever possible, be set up by them. Its contents should change regularly to keep stimulating students with new objects and questions they can investigate and ponder.
- All the signs and cards at the science center should be printed in large, bold lettering for students who have visual impairments. Similarly, the signs should not be placed too high or too low; students who have physical disabilities should be able to read them easily.
- No objects that could pose a danger to students should be kept in the science center—for example, no heating devices or objects with sharp edges. See the section on safety tips in "More Resources for Teachers" at the end of this book. Also see the *NSTA Ready-Reference Guide to Safer Science* by Kenneth Roy (2007).
- The center should include tools for measuring different properties of objects, such as a balance scale, uniform masses for weighing, centimeter sticks for measuring distance, and graduated cylinders for measuring liquid volume. The center can also include other common science tools, such as magnifying lenses, prisms, magnets, and mirrors. The questions and activities should give students reasons for using these tools.
- If at all possible, place a networked computer in the science center. It should be loaded with some meaningful software programs to engage students in problem solving, and the questions posed in the center should often lead students to use the computer as a tool.
- If the science center reflects the theme of the current science unit, set out materials and experiences that extend the students' thinking. For example, for a unit on electricity, set up the science center so that it invites students to construct different kinds of circuits. The center might feature books about electricity and perhaps have some small electrical appliances (unplugged!) for students to take apart and explore.

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graduated cylinder
A device used for measuring liquid volume. In essence, it is a scientific measuring cup—a glass or plastic cylinder calibrated in milliliters.

In the upper elementary school grades, students can largely control the contents and activities of the science center. Science center "crews" can rotate monthly, taking the responsibility for changing some displays and maintaining others, as they see fit. This regular attention helps ensure a regular flow of materials into and out of the center.

For very young students, the teacher can take a more active role in designing the exhibits. Even in these earlier grades, however, you can engage students in designing the science center by offering possibilities and inviting them to share their own special objects from nature.

One first-grade teacher found that her class's science center, which focused on the seashore, was getting *too* exciting, at least in terms of the way students behaved there, so she engaged her students in developing rules for the science center. The teacher felt that any rules she could have imposed on them would have been burdensome rather than effective and helpful, so she let the students consider their own comfort level and come up with reminders that only they could have created. Here are the guidelines the students themselves made up:

1. No traffic jams, please. Three students at a time.
2. Wait your turn and say "please" and "thank you."
3. Share books.
4. Sit the right way.
5. Visit about ten minutes.

With their own rules in place, the students found the science center to be an excellent place to investigate seashore topics independently. Often, during science discussions, these first graders would refer to books they had read in the science center or to questions they had wondered about while exploring the resources there.

Questions and Activities Like the science activity stations described earlier in the book, a classroom science center should have cards (or displayed pieces of paper) that contain questions. For example, if the science center has a collection of acorns, the card could read, "How would you classify these acorns? Why did you classify them this way instead of some other way?" Whenever possible, the teacher should have the students themselves construct the questions when they set up the displays. The students often answer the science center questions in their science notebooks.

4-7a Sample Science Centers from Around the Country

Looking at some science centers that teachers and students have set up in different areas of the country will help you think about ways to connect science concepts with your students' daily lives.

A Third-Grade Science Center in the Northeast This science center contains a collection of seashells in a plastic container as well as the book *Seashells by the Seashore* by Marianne Berkes (2002). An index card on the table next to the shells has the following message neatly printed on it:

> **Can you classify these seashells? In what ways are they the same? In what ways are they different?**

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A Second-Grade Science Center in the Northwest One second-grade student has brought a very large pinecone to class. It becomes part of the science center. The teacher asks the students what they want to find out about this pinecone. The children wonder how much it weighs, where it came from, and why it is so big. As the pinecone is placed on the science table, the teacher writes this on the accompanying question card:

> How many red chips weigh the same as the pinecone? How long is the pinecone? Where do you think it came from? Why is it so big?

The children who wander over to the science center are free to explore any or all of the questions.

A First-Grade Science Center in the Midwest A stuffed, furry yellow chick sits on the science table. The index card asks a science question connected to literature:

> In what way is this baby chick like the real chick in the book we read in class? In what way is it different?

The book mentioned here is Ruth Heller's *Chickens Aren't the Only Ones* (1999).

A Third-Grade Science Center in the Autumn A group of leaves sits on the table. They have different shapes, sizes, and colors. An index card reads:

> What types of trees do you think these leaves came from? Are they from very large trees? Deciduous trees? Coniferous trees? Explain your thinking.

A Second-Grade Science Center A small basin of soapy water is surrounded by pipe cleaners shaped to look like bubble wands. Some are triangular, and some are square. The index card reads:

> What shape is a bubble?

In the same science center, next to a prism, an index card reads:

> Hold this up to the light. What colors do you see?

A Third-Grade Science Center A basin of water invites the students to place different objects in the basin to see if they sink or float. The objects on the table are a marble, a paper clip, a wooden block, and a small ball. The children are allowed to try other objects as well (but dunking peanut butter sandwiches from their lunch boxes is discouraged). An index card asks:

> Which objects sink in water? What happens when they sink?

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A Sixth-Grade Green Science Center One sixth-grade class was studying the quality of water in the local environment. Using samples of water in small, labeled beakers, students tested tap water from the school water fountains, tap water from home, store-bought bottled water, and rainwater. They had litmus paper and red cabbage juice indicators to determine the pH of the various samples. (The pH is a measure of the acidity or alkalinity of a solution. Litmus paper and red cabbage juice both change color in ways that reflect the pH.)

pH
Measure of the acidity or alkalinity of a solution.

As students tested each sample, they recorded the pH of the water on a chart at the science center. Water usually has a pH of 7, which is considered neutral. Water that is too acidic (less than 7) or too alkaline (more than 7) is considered unsafe for drinking. This class learned that about one-sixth of the world's population does not have access to safe drinking water and that these people live predominantly in Africa, Mexico, parts of South and Central America, and parts of Asia (Smolan & Erwitt, 2007).

The science center questions should encourage the students to explore and experiment with the materials at hand. One second-grade science center displayed eyedroppers and a cup of water. Next to them were some pieces of an old newspaper. The card read, "Place a drop of water on the letters in the newsprint. What happens?"

Imagine a science center or science table that changes every few weeks, contains an assortment of objects collected by the students and teacher, and challenges the students to find answers to questions. Since classroom science centers should reflect the lives of the students, it makes sense that they vary with the geographic location of the school and the interests and backgrounds of the students. For instance, classrooms in coastal regions may be rich in seashell collections, and inland regions may have rich rock collections. A school in the Southwest may have a marvelous display of different sands and sedimentary rocks on its science table. This is the sort of informal learning experience in which students can become deeply engaged.

4-8 The Daily Life of the Classroom

When you enter an elementary school classroom, the life of the class is often reflected by the materials that adorn the room. I often look for a science center. When I find it, I spend time exploring the materials on it. Sometimes they tell me only what science unit the students are studying; at other times, though, I learn about the students' own collections and interests. The tacit message I receive from classrooms that have student-generated science centers is, "Science is a regular, meaningful part of the life of this class."

Similarly, in a middle school science classroom, I look for more than the typical scientific equipment and posters. What I want to see is some evidence that the students' own interests and lived experiences have informed their science activities. For instance, the displays may include student research reports that focus on areas of student interest.

The same principles apply to field trips and other outdoor activities. By constructing an informal curriculum out of natural items and events in the students' own world, we make it possible for them to value themselves as scientists and to overcome the traditional factors that alienate many young people from science. We help them understand science content more deeply and more personally as part of a larger picture. Finally, we raise their awareness of their natural environment and the issues it poses for their future life as adults.

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CHAPTER 5

Exploring Matter: Scientific Observations of Everyday Materials

Next Generation Science Standards

- **Crosscutting Concepts:** 1, 2, 3
- **Disciplinary Core Ideas:** 2-PS1-1, 2-PS1-2, 2-PS1-3, 5-PS1-3
- **Science and Engineering Practices:** 4, 5, 6, 7, 8

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 5-1 Understand the importance of direct exploration of materials for establishing scientific thinking.
- 5-2 Recognize the value of students exploring independently at science centers or stations.
- 5-3 Examine the ways that grouping materials can lead to categories that are not always neat.
- 5-4 Discuss the value of recognizing that science concepts can be complex and messy.

Reflection

To Think About:

- What is important about the process of grouping or classifying?
- How are scientific observations different from everyday observations?
- What types of "messy" explorations do you do?
- What do you think is meant by the statement, "Science is not neat"?

5-1 Exploring Matter: Scientific Observations of Everyday Materials

scientific observations
As contrasted with everyday observations, scientific observations are perceptions of the natural world or a phenomenon that are made as part of a specific disciplinary context and students are noticing specific characteristics and recording their observations.

classifying
Sorting objects or ideas into groups on the basis of similar properties.

Scientific study can help us organize our thinking about the enormous diversity of materials—both living and nonliving—that exist in our environment. As we noticed in the icicle experiments done by Mr. Wilson's class in Chapter 2, students can construct fundamental ideas about the nature of objects through direct experience with them. In this chapter, we look at classrooms where students are exploring different types of materials and trying to make sense of them. This sense making often begins with the process of **scientific observations** as we explored in the last chapter. Observing materials can lead to grouping materials with similar properties into the same categories, often called **classifying** or sorting. As you read the stories in this chapter, look for these themes:

- Knowing *why* an object belongs in a particular category is as important as knowing *where* to place it.
- Choosing a category for an object or a concept isn't always simple.
- The science ideas or core concepts and the practices of science are a two-way street—students keep going back and forth from their experiences to their sense making.
- Science can be messy—in more than one way. Often you make a mess when exploring materials. Often, too, the ideas that are generated during the process of classifying are themselves complex and "messy." Some students and teachers like to organize ideas into neat categories, but this can lead to oversimplification of rather complex concepts. Scientific study is *not* neat.

This chapter deals mostly with children in the early grades. In later chapters, you will see how older elementary and middle school students build on the knowledge and skills described here.

In elementary school science, children often learn classifying skills by identifying the properties of materials through careful observation and then comparing and contrasting those properties. This type of scientific observation helps them to learn more about the materials and how they behave in nature. There are many terms we use to describe the material world and scientific observation

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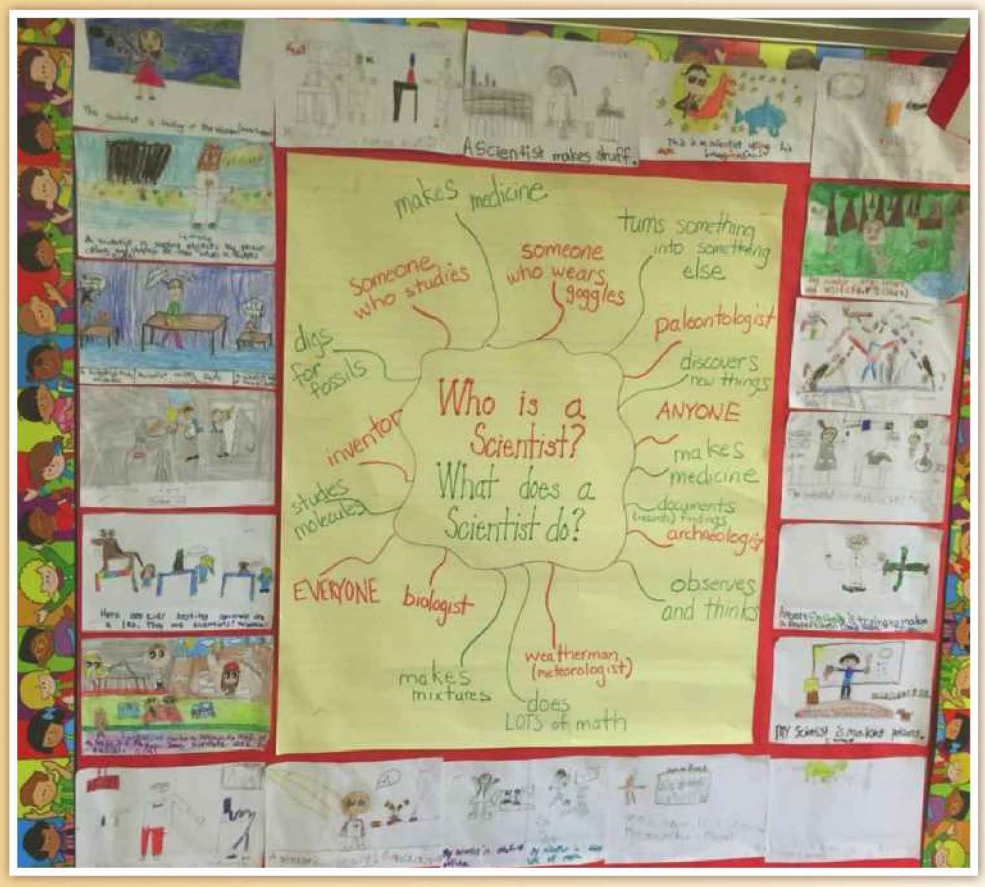
can lead to understanding that materials differ from one another. These terms are size, shape, color, odor, texture, taste, composition, and hardness. *Big*, for example is a *property word*, as is *red*. In developing their classifying skills by using such property words, children are also learning language and communication skills. The following story explores how one teacher used science stations to engage her students in exploring matter and recognizing properties.

SCIENCE STORY

Third Graders Describe Properties of Matter

What does it look like when children explore materials, working independently and finding out about matter through direct experiences? In one third-grade classroom in a middle-class suburb, the teacher sets up stations around the room to introduce her third-grade students to the concepts of shape, size, mass, sinking and floating, and states of matter. They had already learned what matter is and how to describe the properties of matter. Now, they will be testing observable characteristics as a way to extend what they have already learned. When you enter Ms. Toppi's classroom, you are surrounded by words and pictures. On one chart is a concept map with the words "Who is a scientist? What does a scientist do?" (Photo 5.1).



Janice Koch

PHOTO 5.1 Students respond to the central question on this chart and then draw pictures of scientists, which becomes the border for this "thinking out loud" map.

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All around are students' responses like "digs for fossils," "studies molecules," "wears goggles," and "does lots of math." Clearly, Ms. Toppi was brainstorming with the students and recording their responses. Surrounding the concept map are students' drawings, reflecting scientists' activities or at least what they think they do!

Ms. Toppi uses the SMART Board in the front of the classroom to discuss the meaning of the term *matter*. Around the room, there are four stations, each addressing activities related to properties of matter. Ms. Toppi reminds the students that each of these stations require that the students be good thinkers as well as doers. There are twenty students in the class, and it is clear they have had practice working in small groups at different stations before. At the "Exploring Mass and Volume" station, Ms. Toppi discusses "units" of measurement with the students. They have a digital scale to work with, and they get to weigh spherical objects that all look about the same size but weigh different amounts in grams. That understanding between size (volume) and mass (how much it weighs) is a crucial precursor to understanding the concept of density. Ms. Toppi asks, "Which objects look about the same size?" The students show two spherical objects and notice that one feels lighter than the other. "Let's prove it," Ms. Toppi suggests, and when the students place them on the digital scale they are not surprised that one has a lot more mass than the other. The tennis ball is 58 grams and the spherical mini-robot is 188 grams!

At another station, students are working with an aide to determine how buoyant are a group of objects. Will they sink or float, or a little bit of both? The objects are an apple, a pear, a filled soda can, a tennis ball, and a billiard ball about the size of the small spherical mini-robot that was just weighed in the previous station. The students have instruction sheets at each station and record their data. Sinking and floating appear to be straightforward properties; however, the students are engaged with how to determine if an object is *really* sinking if it does not fall to the bottom. Students are asked to predict what will happen to their objects and why they think they will sink or float. Then they record the actual result and try to come up with their own ideas about why the object behaved that way. Ms. Toppi reminds the students that scientists always think about what they observe and this leads them to new investigations.

In a third station, students get to choose from an array of books about matter with titles such as *Solids, Liquids & Gases*, and *Measuring Matter*. This is a reading station and each of the books provides new information for the students. Again, an instruction sheet includes places for students to record responses to questions. I am struck with this station as students are really busy reading nonfiction texts and appear to be enjoying them! This is the "States of Matter" station and students are asked to read about the different states of matter and write interesting facts about solids, liquids, and gases.

At the fourth station, students select objects from a bag and describe the physical properties of the object—is it a solid? What color? How does it smell? What is its size? Their instruction sheet asks them to study the objects closely and thoughtfully and create groups for them. Once again, I am reminded that they are not casually observing the objects but making scientific observations of these objects and grouping them into categories like "blue objects," "bumpy objects," and so on.

The Teaching Ideas behind This Story

- Implementing a station activity requires a great deal of planning. This includes developing names for the stations, creating instructions, and asking oneself "What do I hope the students will learn from each experience?"
- Forming student groups that can work together at each station is yet another challenge, and Ms. Toppi has thought about these groups and organized the students prior to beginning the activity.
- Notice how Ms. Toppi asks the students to *think about* what they are observing. What did they notice? What are their questions? This emphasizes that scientific activity is a lot more than doing things.

The Science Ideas behind This Story

- Scientific observations require a disciplinary context. In this station experience, students are asked to group materials, describe why they chose their categories, and to carefully measure and record their findings.

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- When students compare how the spherical objects "feel," they are asked to prove their thoughts by using the digital scale and recording the masses of the objects. This is a way the students argue from evidence.
- In the sink-and-float station students are asked why they made their prediction and then they compare those predictions to the actual results. This is a way they are observing and reasoning like scientists.

Connections to the Next Generation Science Standards

- **NGSS DCI: 5-PS1-3: Structure and Properties of Matter:** Measurements of a variety of properties can be used to identify materials. (Boundary: At this grade level, mass and weight are not distinguished.)
- **NGSS SEPs:** Students were engaged in *constructing explanations* and *engaging in argument from evidence*. They *obtained, evaluated, and communicated information*.
- **NGSS CCs:** Students recognized *cause and effect* relationships when they measured and tested materials. They considered *scale, proportion, and quantity*.

5-2 Explorations at Science Stations

In the following two science stories, we'll see how some students in the early grades identify certain properties as they attempt to group objects according to their similarities or state of matter. The states of matter—solid, liquid, and gas—sound simple, but they are not always obvious or visible.

SCIENCE STORY

Exploring Solids, Liquids, and Gases

Ms. Harrison's multiage class is in a rural setting, far from the action and resources of metropolitan areas. When I enter, I see that she has set up five stations around the room so the students can work simultaneously in groups. It is late in the school year, and the children have already learned the rules of their classroom setting. They seem comfortable and are functioning well independently. The class has nineteen students, at different stages of development, in grades 2 and 3.

Ms. Harrison has prepared five identical sets of materials—one set for each group of students. Each set has three plastic bags, all the same size. In one bag she has placed a wooden block; another bag holds 8 ounces (1 cup) of water; and the third bag Ms. Harrison has blown full of air. All the bags are closed with twist ties. The only labels on the bags are as follows: All the bags with solid blocks in them are labeled "bag 1," all the bags of water are "bag 2," and all the bags of air are "bag 3."

Ms. Harrison plans for the students, in groups of four, to explore these bags and describe their contents. To introduce the activity, she says, "We have the opportunity to explore some materials today. We are going to observe them in any way we can, and then we will try to classify them. In your science notebooks, write down all the things you can say about these materials."

Ms. Harrison's thinking: *Although Ms. Harrison wants the students to recognize the differences among solids, liquids, and gases, she sees no reason to supply those labels up front. She wants the children to do their own thinking about the classifications, and the labels can be introduced later.*

Ms. Harrison guides the students along: "What are all the things we can say about the materials in bags 1, 2, and 3? Remember to write your observations in your notebook."

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Suddenly, Alena, one of the older students, calls out, "That's easy, Ms. Harrison. One is a solid, one's a liquid, and one's a gas!"

"Yes, Alena, that is one type of label we can give these materials, but I asked all of you to make observations. Let's talk about why one is called a solid, while another one is called a liquid, and another one a gas. Your observations can help us with that."

Ms. Harrison's thinking: *Okay, Ms. Harrison thinks, the labels are more obvious than she planned. Several students already know that these materials are examples of solids, liquids, and gases. But she is hoping for some discussion of the meaning behind the labels. She wonders whether the students will be able to determine what properties are usual for any solid, liquid, or gas.*

As the students examine the three bags and write their observations in their notebooks, Ms. Harrison visits each group. Suddenly, there is a scream. One of the water bags has spilled all over the table and Todd's leg. Another student gets paper towels, and the group cleans up the mess. Todd says, "Sorry!" It appears that the bag broke because he handled it a bit too much or too roughly.

After making sure that Todd does not mind a wet pant leg, Ms. Harrison says, "Sometimes science can get messy, but that's okay. Why don't you put some water in another bag, Todd. Tie it tightly, and go on with your observations."

My thinking: *As I watch the class working, I am impressed with the calm way Ms. Harrison handles the spilled water. Certainly this is not the first time a spill has happened, and it won't be the last. I agree with what she told the class—that getting messy is sometimes a part of doing science.*

When the students appear to be finished writing in their science notebooks, Ms. Harrison gathers their observations and records them on a class chart. Table 5.1 lists some of the students' responses.

TABLE 5.1 Observations by Students in Ms. Harrison's Class

The Block	The Water	The Air
It is yellow.	It is white.	It is light.
It is hard.	It is wet.	I can see through it.
It's a rectangle.	It is drippy.	I can tap it and make it fly.
It has eight corners.	It has no shape.	It has no shape.
It has six sides.	I can see through it.	It doesn't drip.
It can float in water.	I can pour it into a glass.	
I can bang it on the table. It makes a loud sound.	I can squeeze the bag.	
It doesn't change its shape.		
I can't squeeze it.		
It's smooth.		
It is medium-sized.		

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My thinking: *I see that the distinctions among the different states of matter have begun to emerge in the students' minds. Now the lesson is really going beyond the labels.*

Ms. Harrison begins to pull the lesson together by remarking, "Alena said, when we began, that these materials in our plastic bags were a solid, a liquid, and a gas. What do you think about that?" After discussing the question, the students conclude that the air is an example of a gas, the block of a solid, and the water of a liquid. Ms. Harrison tells them these are three states of matter. "Scientists say that matter is anything that has weight and takes up space," she goes on. She urges the students to see if their three samples meet those criteria. Do they all take up space and have weight?

The students agree that the block, the water, and the air take up space, but not everyone is convinced that the air has weight. "How many of you think that we can weigh the air that is in this bag?" Ms. Harrison asks. About half of the students raise their hands.

Ms. Harrison proceeds to blow air into another plastic bag and tie it. She rests a book on the bag of air and invites the children to observe how the air takes up space and supports the weight of the book. She explains that blowing the air into the bag and tying the bag pushes the tiny air particles together. Then she asks, "How can we prove that this air weighs something?"

My thinking: *As I know from other experiences—like the ones described in earlier chapters—the gaseous state of matter is the least concrete for children and the most difficult for them to grasp. I think that Ms. Harrison is wise to pursue the idea that compressed air can be weighed.*

The students aren't sure how to weigh the air. Ms. Harrison takes a double-pan balance and places an inflated balloon on one side of the balance and a deflated balloon on the other side. Before she lets go of the balloons in the pans, she asks the students what they think. How will the scales tip? The students are divided about the outcome.

The inflated balloon tips the scale downward, indicating that the balloon filled with air weighs more than the balloon with no air. Then Ms. Harrison asks the children to blow on their hands, feeling their own exhaled air.

"It tickles," Julia says. "It feels warm," remarks Marika.

Ms. Harrison's thinking: *Ms. Harrison hopes that all these little "air" experiences will help reinforce the idea that air is matter: in addition to taking up space, it has mass, you can feel it, and it can be warm or cold.*

Ms. Harrison continues, "Let's look at the list of properties on our chart. Notice that we had more things to say about the solid than about the liquid or gas. Why do you think that is so?"

My thinking: *I see that Ms. Harrison is beginning to generalize from the block, the air, and the water to solids, liquids, and gases. It is true: Solids have more attributes for students to describe than do liquids and gases, and it is easier for children to come up with property words that apply to solids.*

The students go over their list of the wooden block's properties. They begin to understand that solids have surfaces, shapes, and textures, and that they are easy to measure compared to objects with changeable shapes. Ms. Harrison invites the students to name the solids in their classroom. The students generate a long list of objects: tables, chairs, walls, posters, books, and so forth.

Ms. Harrison then asks, "What liquids do you drink or see every day?" The students generate a long list again. She says, "Let's look at our bags of water. How can we weigh the water?" The students ask her to put one bag on a scale, and she does so for them. She points out that the bag weighs something as well, but its weight will be too small to notice.

"What if we were weighing our water in a cup?" Ms. Harrison asks. Some of the older students remark that they would have to weigh the cup first, then weigh the cup and water together, and then subtract the weight of the cup.

My thinking: *I notice how Ms. Harrison varies her tactics. She asks the students to find examples of solids in the classroom, but when she turns to liquids she realizes that the students will see few or no liquids in the room. So she changes the question into one about their everyday lives. I also like the way she asks them to think about weighing the water in the cup, wanting them to understand that weighing the liquid alone is not that easy. (I am reminded of the students in Mr. Wilson's class who weighed the melting icicles.)*

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For the next day's class, Ms. Harrison asks the students to write down all the solids, liquids, and gases they notice in their own homes. And for each item, they should write down why they think it is a solid, a liquid, or a gas. To guide them, Ms. Harrison distributes writing prompts on small sheets of paper:

Name of Object: _____

I think this is a (solid, liquid, gas) because it _____.

The students each take four sheets and set out to identify four objects in their own homes.

5-3 Finding the Right Grouping Is Sometimes Challenging

SCIENCE STORY

Mysterious Matter

> *Simply noticing the diversity of stuff in the material world can evoke an open-mouthed sense of wonder akin to visiting a zoo filled with animals you have never seen before.*
>
> —Ivan Amato

Ms. Hager, a first-grade teacher in a primary school in southern Florida, is combining 2 cups of cornstarch with 1 cup of water in a large bowl. She is creating an activity that in some ways will be even more challenging than the one in Ms. Harrison's class. She is going to take advantage of the fact that it is sometimes difficult to decide what state of matter an object is in. Sometimes matter can have properties of more than one state.

Before mixing the ingredients, Ms. Hager has invited the students to explore the cornstarch and decide its state. This generates a lot of discussion. The children think it is a powder, and they have a hard time deciding if a powder is a solid or a liquid. Ms. Hager challenges them to think about it but does not tell them the answer.

"Where have you seen this white powder before?" Ms. Hager asks. One student says that her mother uses it to cook. Another student says that his parents use it to diaper his baby brother.

Now Ms. Hager takes 1 cup of water and adds green food coloring to it. Then she adds the water to the cornstarch and stirs the two together. This produces a peculiar green goo. After the students help Ms. Hager cover all the tables in the classroom with newspaper, she distributes a piece of the green goo in an aluminum-foil pie pan to each pair of students. She encourages the students to explore the mixture, discuss it, and express all their possible observations.

The students are delighted. As they quickly discover, the goo looks and feels like a liquid, but it can be shaped into a ball. It looks as if it should splash when they drop an object in it, but it does not. All in all, this "gushy mess," as one student describes it, provides them with a wonderfully tactile experience. As they get it all over the newspaper-protected tables, they come up with many observations about it. One student records in her notebook that the mixture is "soft, smooth, and mushy." Another writes, "It was a little like a solid and a little like a liquid." Still another student observes, "We made green goo. If you hold it in your hand and gently squeeze it—it can drip out of your hand when you let go."

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Ms. Hager's thinking: *Ms. Hager knows that it is important, especially with young children, to provide opportunities for them to explore interesting materials and use language to describe what they are experiencing. And she knows that this mixture will provide a good workout for their skills of observation and description.*

"What happens when you add more water to it?" one girl asks.

"Let's try it!" replies Ms. Hager.

The students observe that adding water makes the mixture more like a liquid. Ms. Hager says that the measurements of the two ingredients are important. Another student wants to add more cornstarch. Again, they try the experiment, and it makes the mixture seem more like a solid. It also turns it a paler shade of green.

Ms. Hager challenges the students to decide what state of matter the green goo is in. They cannot make up their minds. They decide to place it in a new category for their matter unit: "Not Sure."

The students already have a list on the board, and now they add their latest observation to it:

Solids	Liquids	Gases	Not Sure
wood	water	air	green goo
chalk	orange juice	soda bubbles	
blackboard	milk	helium	

They have learned that sometimes materials can fall into two categories— or none at all (Photo 5.2)!

Michael Newman/PhotoEdit

PHOTO 5.2 Literally hands-on! As part of a unit on states of matter, students explore an elastic putty. What state of matter is this?

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As a culminating activity, Ms. Hager gathers the students on the classroom rug and reads aloud to them the Dr. Seuss classic *Bartholomew and the Oobleck* (1949). This story made the green goo famous and gave it its often-used name, "oobleck." The king in the story is bored with ordinary weather and causes green goo to "rain" from the sky. The students giggle at the result and relate it to how sticky and unpredictable this green goo can be.

The Teaching Ideas behind These Stories

- In Ms. Harrison's class, the important distinctions between solids, liquids, and gases *emerged* as the students examined the contents of each bag. Ms. Harrison did not rush to label the materials. Even Alena, the student who called out the correct labels, was missing the point. The main question is, "What does it *mean* when we say something is a solid or a liquid or a gas?"
- When Todd broke the water bag, Ms. Harrison treated the mess as routine—a result of scientifically exploring water. It's important that students see exploration as nonthreatening. Honest explorations are impossible in an atmosphere where students are terrified to have an accident.
- Notice how Ms. Harrison used several techniques to demonstrate that air is matter. This provided multiple opportunities for students to grasp the concept and relate it to their own experiences.
- When Ms. Hager asked the students where they had seen cornstarch before, she was making connections between the science experience and their experience outside the classroom.
- Ms. Hager did not tell her first graders the answer to the state of matter of the cornstarch. She let their dilemma sit with them for a while. As they worked with the cornstarch, they recognized that it must be a solid.
- Inviting her students to explore the cornstarch-and-water mixture was a way for Ms. Hager to encourage them to use descriptive language.
- "Oobleck" is the name sometimes used for the cornstarch and water mixture. Whether or not you call the mixture oobleck, the Dr. Seuss book mentioned in the story offers a great way to connect the science lesson to literature. So does *Horrible Harry and the Green Slime* (1989), written by Suzy Kline.

The Science Ideas behind These Stories

- There are three common **states of matter** that we can explore with students: solids, liquids, and gases.
- **Solids** have a definite shape and can hold that shape for an indefinite amount of time if outside conditions remain the same. Besides shape, children come to know that solids have a definite size, texture, and color and can be easily measured and weighed on a scale.
- **Liquids** have a definite size but no definite shape. Liquids take the shape of their container. The most commonly found liquid on earth is water. Many foods have a large water content—as does the human body.
- **Gases** have neither a definite size nor a definite shape. Gases take the size and shape of their container.
- In addition to solids, liquids, and gases, scientists have identified two other states of matter: (1) *Plasma* is the random array of very hot matter—gases so hot that they no longer resemble any known gases because electrical particles have been stripped away from the central part of the molecules. Plasma is the stuff of which stars are made, and it is the most common state of matter in the universe, but not on earth. A tiny bit of plasma can be found in a fluorescent light bulb. (2) The *Bose-Einstein condensate* is, in a way, the opposite of plasma because it occurs at ultralow temperatures, close to the point where atoms are not moving at all. Although its theoretical existence was predicted early in the twentieth century, the Bose-Einstein condensate was not actually created in a laboratory until 1995.

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- Air is a mixture of gases. While to our bodies oxygen is the most important part of the air, only about 21 percent of the air is oxygen. Air is about 78 percent nitrogen.
- Cornstarch is a powdered solid. Even though it does not have rigid surfaces, a clump of cornstarch powder stays together on a surface in its own small mound.
- The cornstarch and water mixture is actually a **suspension**; the solid particles are literally suspended between water particles.
- Just why the cornstarch and water mixture has such odd properties, acting sometimes like a liquid and sometimes like a solid, remains a mystery to scientists. There are several theories involving electrical charges and a theory about molecular size—but no conclusions.
- Frequently objects do not fall into neat categories. Understanding that the study of science does not always provide clear answers is an important way to make school science more like real science.

Connections to the Next Generation Science Standards

- **NGSS DCIs:**
  - **2-PS1-1: Structure and Properties of Matter:** Different kinds of matter exist and many of them can be either solid or liquid depending on the temperature. Matter can be described and classified by its observable properties.
  - **2-PS1-2 and 2-PS1-3: Structure and Properties of Matter:** Different properties are suited to different purposes.
- **NGSS SEPs**: Students are *engaged in arguing from evidence* and *obtaining, evaluating, and communicating information*.
- **NGSS CCs**: Students were observing *patterns* as they grouped and classified matter; they examined *cause and effect* as they sought explanations for the states of matter of the oobleck.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- For the activity that Ms. Harrison's class engaged in, what other materials might you use in place of the block of wood, the water, and the air in the plastic bags?
- Think about gelatin. What state of matter is it? What about mayonnaise? Oatmeal?
- How do *you* feel about messy environments? What kind of assistance would you need to pull this off in an orderly fashion?

5-4 If It's So Messy, Can It Be Science?

states of matter
The basic forms in which matter is found: solid, liquid, and gas (and a state that is rare on earth, plasma).

solid
A state of matter with a definite size and shape.

In Ms. Harrison's and Ms. Hager's classes, the children were engaged in what we might call messy investigations. They were messy in a literal sense: the water spilled, the green goo got all over things. In fact, if you try the cornstarch experiment, it is a good idea to cover the tables or desks as Ms. Hager did. Luckily, the mixture will wash off readily with plain water.

Second, there was a metaphorical messiness. The green goo behaved like a liquid sometimes and like a solid at other times. You may think that classifying

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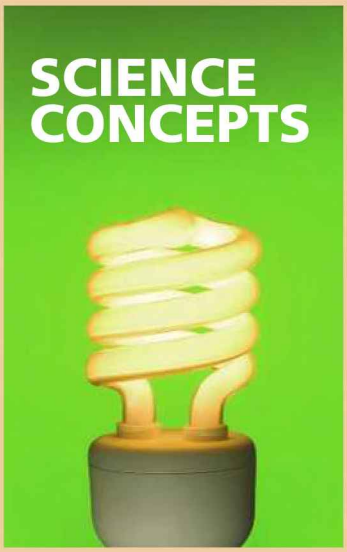
Matter and Energy



The exploration of nonliving materials belongs to the branch of school science called **physical science**. The study of physical science encompasses the interactions between matter and energy.

As we saw in an earlier chapter, **matter** means anything that has weight and takes up space. If you can measure it and weigh it, it is usually matter. By energy, we mean the ability to produce a change in matter. Scientists define **energy** as the ability to do work, and *work* is defined as a force moving through a distance. So, for example, energy is needed in order to push a rock off the edge of a cliff. The amount of *force* that is used and how far the rock moves is a measure of how much energy is needed to move the rock.

Matter and energy are two very broad categories in which the diverse materials of the world can be placed. Matter can be further described by its different states, such as solid, liquid, and gas. By the upper elementary grades, students often begin to learn about chemical composition as well, distinguishing elements from compounds and mixtures. By middle school, students learn about atomic structure and its implications for the ways materials combine with one another.

An **element** is the building block of all matter. The simplest form of matter, an element is made up of only one type of material. Examples of elements are iron, nickel, gold, silver, oxygen, hydrogen, helium, carbon, and mercury. There are ninety-two naturally occurring elements in the universe, and about fifteen others that have been produced by scientists in laboratories. The smallest part of an element that still has the properties of that element is called an **atom**.

A **compound** is a combination of two or more elements in a definite proportion. For example, water is H_2O—two parts hydrogen to one part oxygen. The smallest part of a compound that still has the properties of that compound is a **molecule**. Molecules are made up of atoms. Salt, carbon dioxide, and water are three common compounds. When compounds form, the elements that comprise them lose their original properties.

Finally, a **mixture** is any combination of elements, compounds, and other mixtures. Because there are only ninety-two naturally occurring elements, most matter that we encounter is either a compound or a mixture.

Similarly, there are many forms of energy, and by the later elementary grades students commonly begin to distinguish them. For example, what do you think of when you think of energy? Well, you may think of the energy you exhibit when running or playing tennis. That type of energy is the energy of movement. Scientists call the energy that an object has because it is moving **kinetic energy**. A moving car, a falling rock, and a strong wind all have kinetic energy.

Objects can also have energy when they are not moving. The stored-up energy that your body has when you are sleeping on the night before a big race is called **potential energy**. In most cases, potential energy derives from position in space. A rock about to fall off a very high cliff has greater potential energy than a rock about to fall off a low cliff. The first rock is higher, so it can move farther and therefore has a greater amount of this potential energy. Students can readily learn this idea, just as they learn about gravity, which causes both rocks to gain speed as they fall.

Do remember, however, that it is less crucial that students memorize the definitions for matter and energy than it is that they understand *how to think* about making order out of the diverse materials we encounter in nature.

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liquid
A state of matter with a definite size but no definite shape. A liquid takes the shape of its container.

gas
A state of matter that has no definite shape or size. When a gas is poured into a container, it spreads out until it has the same size as the container and takes the shape of the container.

suspension
A mixture in which solid particles do not dissolve but literally are suspended in a liquid.

physical science
The branch of elementary school science that includes the exploration of nonliving materials, their interactions, and interactions between matter and energy.

matter
Anything that has mass and takes up space.

energy
The ability to do work.

element
A substance made up of only one type of material. The simplest form of matter, elements are the building blocks of all other substances. There are ninety-two naturally occurring elements in the universe and about fifteen others that have been produced by scientists in laboratories. Iron, nickel, gold, silver, oxygen, hydrogen, helium, carbon, and mercury are all elements.

atom
The smallest part of an element that retains the properties of that element. There are ninety-two different kinds of atoms found naturally on earth. The atoms of each element are exactly the same as one another and different from those of any other element.

compound
A combination of two or more elements in a definite proportion. For example, water is H_2O—two parts hydrogen to one part oxygen.

objects, including living things, is a neat and clear process. It is not. As you will see later in this book, there used to be two kingdoms of living things, and now we have five kingdoms. The more we know about things, the more categories we need; and sometimes, when our categories fail us, we end up with a puzzle, at least temporarily.

Let's look in more detail at these two types of messiness and examine their implications for doing science with children.

5-4a Messiness in the Classroom

Often new teachers find themselves making a mess with their students as they engage in science experiences, just as Ms. Hager and Ms. Harrison did. Should you worry about this?

Several years ago, while I was visiting a suburban elementary school in the Midwest, the principal said, "I can't wait to take you to our science room. We have a science teacher who is so wonderful that when you walk in her room, you can hear a pin drop."

"When the children are in there?" I asked.

"Oh, yes," the principal replied.

I knew I was in trouble at that school. My science projects tend to make the children excited and rather noisy. When I saw the classroom, my fears were confirmed. Not only was the place too quiet, it was too neat. I thought that meaningful exploration could not possibly be taking place if the room was dead quiet and perfectly neat.

Sometimes, new teachers who want to engage their students in a student-centered, activity-based science learning environment are intimidated by messy materials and by what appears to be disarray. It is true: When students are using materials, working in groups, and trying to solve their own problems, the classroom will look a bit messy and sound a little noisy. But those are good signs. They are indications that active learning is taking place and that the students are taking charge of their own experiences—with guidance and coaching from their teacher. Sometimes, an assistant in the room can help you plan for cleanup.

Think back to Chapter 2, where you read about Mr. Wilson's students working in groups with icicles—weighing them, melting them, weighing them again, and so on—while Mr. Wilson walked around the room to make suggestions and ask questions. During this activity, do you think the room looked neat and perfectly arranged? I can tell you that it didn't. Some of the melted water spilled, shirt sleeves got wet, and for a while it seemed that pie pans and wadded-up paper towels were scattered everywhere. But these were signs of important activity.

Sometimes a messy room is just a part of doing science with children. So is a time for cleanup. When an activity is completed for the day, the teacher can assign students tasks that make the room cleanup easier to handle. Occasionally, if your class grows somewhat messy or noisy during a science activity, you may encounter criticism from an administrator or a parent. If so, be prepared to explain what the students are doing and why, and don't be intimidated.

You'll need to make certain, of course, that your students' activities and explorations are not dangerous in any way (see the feature "Safety Is Elementary"). Being safe, however, doesn't require perpetual neatness. The science education reform movement recommends that you use a variety of materials and activities to engage students in doing science. It is understood that this process will not always be tidy.

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Safety Is Elementary

Sometimes school teachers, particularly those in elementary school, are wary about doing science because they lack training in safety procedures. Safety is indeed a very important concern.

The National Science Teachers Association (NSTA) has published several handy guides, such as *Safety in the Elementary Science Classroom* (2002). This guide, available on the Internet, includes what to do in case of an accident, how to help students protect their eyes with appropriate goggles, using plants and animals in the classroom, taking field trips, fire prevention and control, storage and labeling of materials, the safe uses of equipment, and a handy safety checklist. Other publications from NSTA include *Safety in the Middle School Science Classroom* (NSTA, 2004), *Inquiring Safely: A Guide for Middle School Teachers* (Kwan & Texley, 2003), and *Exploring Safely: A Guide for Elementary Teachers* (Kwan & Texley, 2002). All of these are available at the National Science Teachers Association website.

molecule
The smallest part of a compound that still has the properties of that compound. Molecules are made up of atoms.

mixture
Any combination of elements, compounds, or other mixtures. Because there are only ninety-two naturally occurring elements, most matter consists of either compounds or mixtures.

kinetic energy
The energy of motion; that is, the energy that an object has because it is moving.

potential energy
The energy an object has because of its position; stored-up energy. When potential energy is set free, it is changed into kinetic energy.

5-4a Keeping It Complex

After reading about Ms. Hager's class, you may be wondering why she involved her students in an activity that did not result in a clear classification of the strange green matter they created from cornstarch and colored water. What is the point of having first graders investigate something that is a little like a liquid and a little like a solid?

First, remember that teaching science entails getting students excited about new materials and the ideas they provoke. We want students to be engaged and eager to explore their own questions and create possible solutions, thus building their own meanings. However, engaging students in their own thinking often exposes the complexities of a subject matter. Students may come up with questions that they cannot answer, or that we as their teachers cannot answer. Sometimes they may even raise questions that the most accomplished scientists in the world have not been able to answer.

"Keep it simple" is a standard phrase of advice we often hear. Do we dare, then, as teachers, to keep it complex (Duckworth, 1991)?

I think we can dare—and we ought to. Doing so is an exciting challenge for science teachers. We must not run away from complexities. We want to foster deep understandings of science content. We need to help students feel comfortable with the known and the unknown. We want them to understand that the process of scientific exploration does not always lead to a single right answer. If they become convinced that science is just a series of collected facts about the natural world—facts without ambiguities and uncertainties—they have missed the point, and our teaching has missed the mark. To sum it up neatly: In the real world, science sometimes offers answers that are *not* neat.

In the case of classification, what we know about children's development suggests that they gradually learn more complex classification systems as they mature (Siegler & Alibali, 2005). How useful, then, to challenge them with green goo—a type of matter that can fit into two categories at the same time! This type of classifying activity can help prepare them for more sophisticated classifying schemes as they continue their science experiences in later grades.

What students learn through "messy" science can have broad implications (see Photo 5.3). After all, our own lives are not always neat, simple, and absolute, and the world we live in is complicated. If we can help students

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PHOTO 5.3 Doing science sometimes means getting messy. Here, some younger students explore the properties of soapy water.

become genuine explorers and investigators, willing to confront complexity and try out their own ideas for making sense of it, we will have taken a big step in preparing them for adult life. Remember, the scientific process involves testing an idea, evaluating evidence, asking a question about how the world works, and sometimes discovering how difficult it can be to find an answer!

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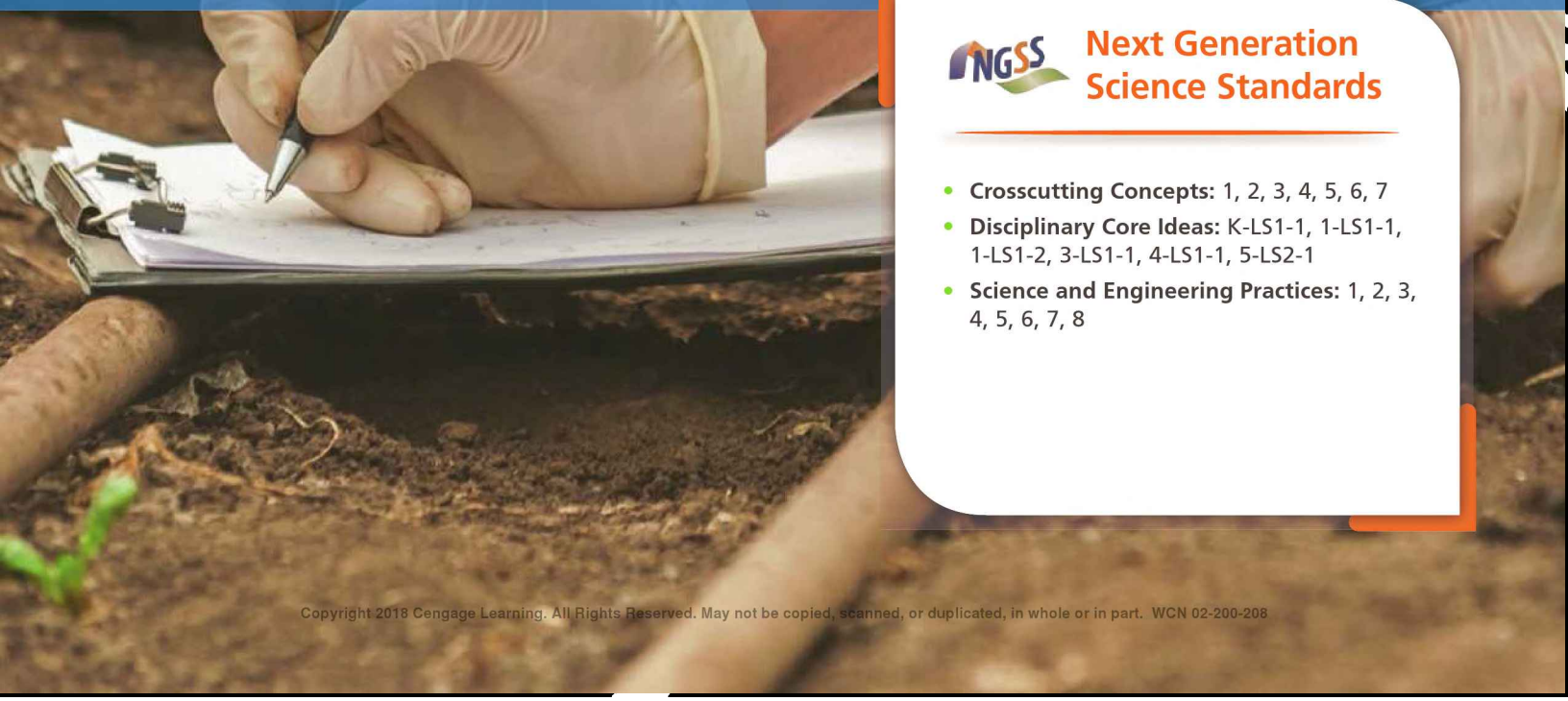
CHAPTER 6

Plants and Animals and Extended Investigations



Next Generation Science Standards

- **Crosscutting Concepts:** 1, 2, 3, 4, 5, 6, 7
- **Disciplinary Core Ideas:** K-LS1-1, 1-LS1-1, 1-LS1-2, 3-LS1-1, 4-LS1-1, 5-LS2-1
- **Science and Engineering Practices:** 1, 2, 3, 4, 5, 6, 7, 8

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 6-1 Understand the scientific meaning of "being alive."
- 6-2 Recognize the value of students' direct experiences with living things.
- 6-3 Discuss the importance of understanding the seed to plant to seed life cycle.
- 6-4 Examine the benefits of investigations over time like those in a school garden.
- 6-5 Discuss the benefits of exploring earthworms.

Reflection To Think About:

- What experiences, if any, have you had with planting seeds, indoors or outside?
- What do you think it means to be "alive"?
- What is the point of a class science exploration that takes days or weeks to complete?
- What is your reaction when you encounter earthworms? Have you ever handled a worm?

You may remember the first time you planted a seed and watched it develop into a plant with a stem and leaves and sometimes even a flower, depending on the type of seed it was. You may still be planting seeds in a home garden or window box. Plants and their growth and development remain a fascination for many home gardeners. All living things, including humans, share the common thread of growth and development over time. This change over time is particularly exciting for students to explore.

Providing opportunities for elementary and middle school students to interact with living things helps to instill an appreciation of the complex processes involved in sustaining life. It also reminds students of the world outside of the classrooms and electronic virtual environments. By bringing a little slice of nature into your classroom, you are helping students to wonder about the outdoors. Many people believe, too, that multisensory activities with objects of nature help to stimulate students' imaginations and their intellectual development (Moore & Hong, 1997). Further, for young people to become stewards for our planet, as you read in the previous chapter, they must be exposed to the diversity of living things on the earth and understand how even smallest of organisms contribute to the delicate balance of nature. This green science agenda is part of our focus as we seek to engage school children with living things in the classroom.

In this chapter, we first look at young children as they experiment with seeds and small living organisms. Then we examine how the activities can change as students reach higher grades. Notice from the stories in this chapter how the complex relationships between living things and their environment are explored more and more deeply as students mature. This is referred to as a learning progression.

In the stories of students in the third grade and higher, you will see an emphasis on *scientific explorations over a period of time*. You'll see students working in pairs or small groups, collaborating with their teachers and with each other to exchange ideas and discoveries.

When we think about an investigation that is ongoing over a period of days or weeks, we return to the idea that understanding science is more than knowing facts. Students build new knowledge and understanding based on what they already know. Hence, we need to

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imagine classrooms that are sometimes noisy, where students are challenging each other and asking questions about the materials with which they are interacting. In these classrooms, the teacher challenges students to make observations, investigate their ideas, and modify and refine their existing concepts based on their interactions with the science materials and with their peers. In this way, through the structured guidance of their teachers, the students are taking control of their own learning (Olson & Loucks-Horsley, 2000). In the stories that follow, watch how the students interact with ideas about living things and with actual plants and animals. Many young people are not sure about the response to the simple question posed by the first stories: "What does it mean to be alive?"

6-1 What Does It Mean to Be Alive?

The science idea of "living" versus "nonliving" has its own special magic for children, and they often wonder on their own what it is that makes something alive. There are many ways you can draw on this natural curiosity to spark a class discussion. In the following two stories, we'll see how some first and second graders approach the subject.

SCIENCE STORY

What Makes a Rabbit Real?

One day, I bring a velveteen rabbit to a class of first graders, along with the famous children's classic *The Velveteen Rabbit* by Margery Williams (1922). In this book, a stuffed rabbit comes to life in the eyes of a little boy who loves him so much that, for him, the rabbit is real. When the stuffed rabbit is old, a fairy makes him a real rabbit—"real to everyone." Released in the woods, the velveteen rabbit is a stuffed toy no more; he is at home with the other rabbits.

I read the book to the class. They are absorbed and attentive—it really is a good story. Afterward, I hold up my own stuffed, velveteen rabbit with both hands. It has a button nose and no hind legs.

"In what ways is this rabbit like a real rabbit?" I ask.

Many of the first graders respond. "It is soft and brown like a real rabbit." "It has two ears." "It has two eyes." "It has a white tail." "It is furry."

"In what ways is it *different* from a real rabbit?" I ask.

Again they have many good ideas: "It doesn't move." "It doesn't breathe." "It has no hind legs." "Its nose is a button." "It doesn't eat or drink water."

"What wonderful observations," I remark. "Let's think about what a real rabbit needs to stay alive."

My thinking: *The question of what is alive is a profound one. I want to establish a major science idea here without "talking" it to the students, so I use same-and-different comparisons to help them make sense of the properties of the stuffed animal and of a real animal. Besides exploring the science idea, I hope to build their process skills as they observe, reflect, and compare.*

The students respond that a real rabbit would have to eat and drink and breathe. So they seem to know that food, water, and air are necessary for a real rabbit to stay alive.

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"So what about this real rabbit?" I wonder out loud. "We know what it takes in. Does it give anything off?"

The students ponder this.

"Let's think about breathing," I say. "When we breathe in, does the air *stay* in?"

"No," one student calls out. "We breathe out too."

"And the rabbit?"

The students all agree that the rabbit breathes out just as they do. Two of the girls, who have petted real rabbits, remember that they could feel the rabbits' breath on their hands.

Then we discuss whether rabbits give off anything else. I'm looking for them to realize that if the rabbit takes in water and food, it must also give off wastes. One of the girls with prior rabbit experience suggests that a real rabbit would "go to the bathroom."

"Sure," I say, accepting this euphemism. "Why do you think it would have to?"

The children aren't sure. Then one student says that if a rabbit kept eating and eating without going to the bathroom, it would explode. Though others immediately label this idea as "gross," it seems that an important idea may be taking shape in their minds: when something is alive, it takes in things from the environment and gives off things to the environment.

On another day, in a second-grade class, I have a similar discussion, but this time I've brought in a silk plant and a real plant. With plants, it is often more difficult than with animals for young children to grasp what makes them alive. (On the other hand, it is easier to have a real plant available in class than a real rabbit.)

I ask, "In what ways is the silk plant like the real plant? In what ways are they different?"

The children are quick to observe that we do not have to water the silk plant, and it cannot grow. It always remains the same size and color. Some children remark that the silk plant "won't die." That comment brings us to the idea that things that are not living cannot die.

Some children also say that the silk plant looks so real that it is hard to tell it is a fake. I ask, "What could you do to tell if it were living or nonliving?" The children respond that they could feel the leaves and then would know whether it was fake.

"How do real leaves feel?" I ask. Now the responses are limited. The children are not sure how real leaves feel, although one student says "waxy." In general, they just know this plant does not feel real.

They persist in their comparisons: "The plant is not real because we don't have to water it." One student offers, "It is not in real soil." Still another suggests that "nothing will happen to it in the dark"—getting back to the idea that it cannot die.

> ***My thinking:*** *The idea that living things grow and change develops with maturity. Many times the students hear the word "grow" used in the context of nonliving things, as in the phrase "growing crystals." I am hoping to nurture the idea that for something alive to grow, it needs resources—stuff from the environment around it. Hence, I am pleased that these students seem to get the idea that this silk plant requires no care—no "stuff."*

Sometimes young children think that even a real plant is not alive. "It is not moving," they may say. "It doesn't eat!" is another common response. This alternative conception is an understandable one that develops as young children apply ideas about animal life to plants. In such cases, it is useful to remind the children that since the real plant needs materials from the environment—like water and sunlight—in order to grow bigger, the chances are that it is alive.

The Teaching Ideas behind These Stories

- A stuffed animal or an artificial plant makes an excellent prop for discussing the nature of living things. However, it is also helpful to have a real counterpart available to provide students with opportunities for observation and comparison.
- Students come to school with many ideas about what is living and what is not living. Often, though, some of these ideas are alternative conceptions. By allowing students to express their ideas, you can discover these alternative conceptions and help the students to change them.
- In addition to using props like stuffed animals, you may want to ask students to name and discuss living and nonliving things in their own environment.

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The Science Ideas behind These Stories

- Living things are distinguished from nonliving things by their interactions with the environment. That is, they take in materials from the nonliving environment, and they give off materials to the environment.
- Using the materials they take in from the environment, living things carry on life processes that give them the energy for growth and development. Without these interactions with the environment, living things could not grow and change over time. (Human life processes are explored in Chapter 10.)

Connections to the Next Generation Science Standards

- **NGSS DCIs**
  - **K-LS1-1: Organization for Matter and Energy Flow in Organisms:** All animals need food in order to live and grow. They obtain their food from plants or from other animals. Plants need water and light to live and grow.
  - **1-LS1-1: Structure and Function:** All organisms have external parts. Different animals use their body parts in different ways to see; hear; grasp objects; protect themselves; move from place to place; and seek, find, and take in food, water, and air. Plants also have different parts (roots, stems, leaves, flowers, and fruits) that help them survive and grow.
- **NGSS SEPs:** Students were *using models*, *engaging in argument from evidence*, and *constructing explanations*.
- **NGSS CCs:** Students examined *structure and function* and considered *cause and effect* relationships as they examined *patterns* for living and nonliving things.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- If no rabbit is available in your school, what other animal(s) might you use?
- What are the wastes given off by green plants? Why are these wastes important to other living things on the earth? (In later stories in this chapter, you'll see how students discover the answers.)
- In what ways do plants grow and change?

6-2 Plants and Animals in Your Science Center

Often, as with the velveteen rabbit and the silk plant, we can bring in objects or animals from outside the classroom to use in activities concerning the properties of living things. But it is also important to have living plants and animals in your classroom on a daily basis—as many as you are comfortable having and as local regulations allow.

Some localities have restrictions on animal use based on concerns about allergies or infections, not to mention the difficulties posed by caring for classroom pets. Even so, there are usually several options. For instance, you can legally keep fish of many varieties. Students often marvel at these vertebrate creatures that live so comfortably below the surface of the water. A calico fantail fish is a variety of goldfish that makes a wonderful classroom pet (Photo 6.1). They are very colorful, and with their large, forked caudal fin, they require a freshwater 30-gallon tank and a filtration system. What makes the calico fantail special is that, over time, it can respond to people as they approach the tank, and they are very funny to watch. They eat flake food and actually have a personality—for a fish, that is!

You can also have various types of invertebrates in your classroom. As you will discover in a story about earthworms later in this chapter, invertebrates tend to be easier to care for than vertebrates and are subject to fewer restrictions.

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Ed Isaacs/shutterstock.com

PHOTO 6.1 A Calico fantail goldfish makes a fine classroom pet. It is distinguished by its forked caudal fin.

Having plants and animals in your science corner makes them part of the daily life of your classroom, so students can observe and care for them regularly. These examples of living things can also help connect science to your students' environment outside the school, especially if you encourage the students themselves to bring in plants that interest them. (It is probably not a good idea to encourage them to bring in animals!)

Finally, keeping living things in the science corner can build students' enthusiasm and provide opportunities for more extended activities, such as those described in the following stories.

6-3 From Seed to Plant

The following two Science Stories illustrate the importance of understanding the seed to plant to seed life cycle (Photo 6.2).

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PHOTO 6.2 Students marvel when a small seed germinates and produces a new plant. They compare their plant's growth as they explore life cycles.

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SCIENCE STORY

A Failed Experiment

Over the past week, Mr. Bauer, a first-grade teacher in a city environment in the Midwest, has kept some popcorn kernels in the class's science corner with a card asking students to identify them and think about where they come from. Now he collects a wider assortment of edible seeds—pumpkin seeds, sunflower seeds, and pea seeds—for his students to explore and plant. He distributes cups of the seed mixture, and the children work in pairs to explore these objects.

"What are all the things you can say about these things?" Mr. Bauer begins. The children respond mostly with property words: "Some are green." "They are small." "They are hard." "You can eat them." "You can cook them." "Some are white. Some are yellow."

One student, Bethanne, says, "They're seeds. You can plant them, and they will make a new plant." The students agree that seeds can grow new plants, though some are not sure that popcorn and peas belong in this category.

Mr. Bauer asks, "Where do you find these things?"

Some of the children answer, "The supermarket." Mr. Bauer then probes, "Well, where does the supermarket get them?" The children aren't sure. Some say that corn seeds come from corn plants and that pumpkin seeds come from pumpkins, but they are unsure how the seeds got to the supermarket.

Mr. Bauer asks the students to draw pictures of their seeds. Some label the drawings with the names of the seeds.

Mr. Bauer's thinking: *Mr. Bauer is interested in having the students explore the seeds before they select one to plant in a cup of soil. He wants to encourage the children to notice things about seeds and to reflect on where they come from.*

Mr. Bauer explains, "We are going to plant our seeds. What will we need?" The children say that they will need a pot of soil and water. Some say that they will need to place the pot in the sun. Their prior knowledge definitely includes some basic understanding of plants.

Mr. Bauer now invites each student to take one seed apiece and plant it in a paper cup filled with soil. The children do so. With Mr. Bauer's guidance, they place their seeds about 2 centimeters below the surface, moisten the soil with water, and place the cups on the window ledge of the classroom. In the following days, they check the cups to see what is happening.

The experiment meets with great success. All the cups sprout a new plant—except for one cup that belongs to a student named James.

Mr. Bauer's thinking: *Worried that not all the seeds would germinate, Mr. Bauer has planned ahead by planting several cups at home. Early one morning, he makes a quick substitution, replacing James's empty cup with a cup that has a little seedling in it. He wants James to experience the same success as the other students.*

That morning, James appears amazed to find that his seed has finally grown. Mr. Bauer is delighted at James's reaction but also puzzled at James's absolute astonishment. Nevertheless, later that afternoon, Mr. Bauer remarks to James that seed growth is often seen as a great miracle and he can understand James's joy.

"It really *is* a miracle," replies James. "I ate the seed!"

In the following story Ms. Fraser's class will explore the structure of a seed, and this interaction holds the promise for lots of questions and significant science ideas. The children are beginning to see that living things grow and change and can produce other living things!

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SCIENCE STORY

What's Inside a Seed?

I am visiting Ms. Fraser's third-grade class in a suburban area in the Southeast. Ms. Fraser's third graders have been exploring plants that grow in their community. Their science corner is full of examples. Today they are going to examine the seed of one such plant, inside and out.

Overnight, Ms. Fraser has soaked some lima beans (called "butter beans" in this Southern community). She has provided paper towels, foil pie pans, and magnifying lenses for students to use. She also has a batch of beans that she has not soaked overnight. She holds these up to the class, and all the students recognize them as butter beans.

"Why do you suppose these butter beans are hard on the outside?" she asks.

One boy answers, "To protect the baby plant inside."

"How do we know there is a baby plant inside?" Ms. Fraser asks.

"Well, it's a seed," the same boy replies. "Seeds have baby plants inside."

Ms. Fraser challenges him, "Okay, but we are doing science, and we need proof. What shall we do to prove your idea?" At this point a girl says, "Some seeds don't have a baby plant inside. They're empty."

My thinking: *Good point, I think. This reminds me of Mr. Bauer's problem when he worried that some seeds would not sprout.*

Ms. Fraser asks the students how they can find a baby plant inside the bean, and they understand that they need to open the bean up. Now she shows the class the soaked batch of butter beans, and they notice how different these look from the unsoaked beans. (When a lima bean is soaked in water, the seed coat, which is a thin protective outer layer, peels away. The lima bean then is softer, and its two halves are more obvious.)

Ms. Fraser divides the class into pairs of students and invites each pair to take two or three soaked beans, some paper towels, a pie pan, and a magnifying lens. Ms. Fraser asks them to draw pictures of the insides of their beans. Also, she points out some books about seeds that she has gathered from both the class library and the school library and invites the students to use them to label their drawings.

Ms. Fraser's thinking: *To encourage the children's own research, she does not tell them which parts of the seeds to label or where exactly in the books to find the names they need.*

As each pair of students examines the inside of a lima bean, they notice a tiny, leaflike structure: the baby plant itself. Their magnifying lenses help them see the details of this baby plant. They draw it and label it "embryo," as it is called in the reference books. The embryo is embedded in the two thick halves of the bean seed. They label these thick halves **cotyledons**, again following the books. The science books have large, clear drawings of the inside of a lima bean seed, such as the one in Figure 6.1. The students look for these drawings to find the labels.

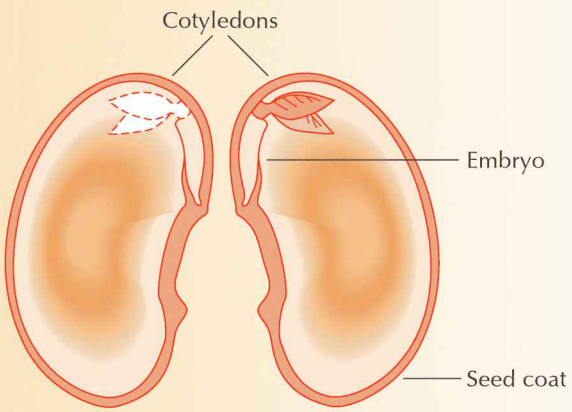

FIGURE 6.1 The parts of a seed, revealed by dissecting a soaked lima bean

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Ms. Fraser visits the students as they are working and asks questions. "What do you notice?" she asks. "Why do you suppose there are two halves to the seed?" One pair of students wants to know how the seed can produce a new plant. Ms. Fraser addresses this question to the class, explaining that they can have the opportunity to actually observe how the seed grows into a new plant right inside a plastic bag. The students are intrigued and excited.

The Following Days: Germination Bags

The next day, Ms. Fraser brings another batch of presoaked butter beans to class. She invites the students to join their partners and take a couple of presoaked beans, a small resealable plastic bag, and some paper toweling to their desks. The following instructions are written on a chart that is placed at the front of the classroom for all the students to see:

> *Place a flat, moist paper towel in the bag, folded, like a lining for the bag. You may get some water from the sink in the classroom. Make sure the towel is not dripping wet. Place two presoaked butter beans inside the bag between the paper towel and one side of the bag. Put a staple on either side of the seed to hold it in place.*

Ms. Fraser herself uses a large resealable plastic bag. In this one bag, on moist paper toweling, she places a lima bean, a pumpkin seed, a bush bean, and a corn seed. She then staples the seeds in place so they will not shift in the bag (Figure 6.2).

> ***Ms. Fraser's thinking:*** *While the students are setting up their investigations with their lima beans, Ms. Fraser will model the germination of several seeds. Students will see that seed growth has certain common properties regardless of the type of seed.*

Ms. Fraser asks the students to decide where they will hang their germination bags. **Germination**, she tells them, is what we call the process of seeds sprouting and beginning to grow. Do the students want their bags to hang in the well-lit classroom on the cork board—or in the dark, inside a closet? Should the plastic bag be laid down on a shelf? On the window sill? Somewhere else?

> ***My thinking:*** *I notice that the only rule Ms. Fraser has given the students for the care of their bag and seed is that they should keep the paper towel moist. The other choices are for them to make, although she is helping them to see their options.*

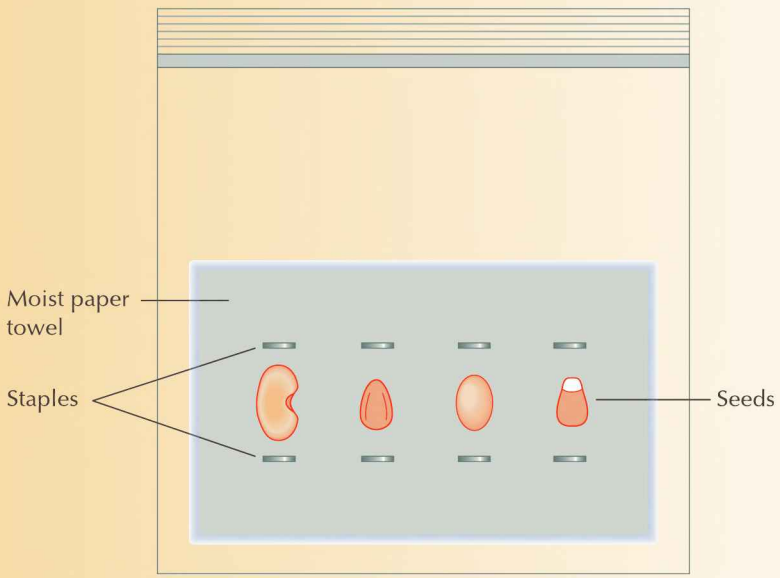

FIGURE 6.2 Ms. Fraser's germination bag

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> *Riddle: I am very little. I can be different colors. I grow tall. I make plants. What am I? Answer: A seed.*
> —ANDREA P., THIRD GRADE

After placing name labels on their bags, the pairs of students engage in extended discussions about where to hang the bags. Some students insist that the seeds need light, while others believe the seeds will grow in the dark. One girl points out, "It is dark under the soil, and the seeds grow there." Some of the partners disagree with each other, but they work out compromises. In the end, some of the bags are hung with pushpins on the cork board in the classroom, and others are placed behind closet doors where there is no light. Ms. Fraser suggests that all the students write down in their science notebooks exactly what they did and what they think will happen.

Ms. Fraser's thinking: *Ms. Fraser wants the students to gather their observations about the seeds in the bags over the coming days and use them to reach some understanding about seed germination. She also wants the students to design their experiment any way they choose. She knows that the conditions that are needed for a seed to begin sprouting are often subject to alternative conceptions—the most common of these being that seeds need light to grow. Privately, she hangs her own germination bag in a dark closet, just in case no one else chooses to place a bag in the dark.*

Each day the students observe evidence of germination. Like a miracle, the young sprouts appear, right inside the plastic bags. The roots grow downward, regardless of the position of the plastic bag. The young stem grows in the opposite direction from the roots. The students observe how thin and willowy the roots are in contrast to the thicker and stronger stem. The students come to learn that the paper towel should be kept moist, but the lighting conditions are unimportant.

The students continue to experiment with the amount of sunlight the baby plants need. In the following days, the plastic seed bags continue to hang all around the classroom. Each day the students monitor the seed growth. Each day the process of germination and growth is visible to them, no longer a well-kept mystery in the dark recesses of a pot of soil.

When the green leaves have emerged and the sprouting seeds can no longer be contained in the plastic bags, the students transfer each germinated seed to a cup of soil. They carefully place the roots in the soil and pack the baby plant in with their fingertips. They water their plants and observe the continuing growth.

After about ten days, some differences are evident. Although the seeds germinated and the early seedlings grew regardless of the light conditions, the plants with leaves do well only in the light. In fact, the students begin to observe that their new green plants will *not* survive in a dark place. They do not understand why as yet.

On day eight of this seed-growth investigation, a student poses the question, "Why will the seedling grow in the dark, but the baby plant with sprouted leaves needs sunlight?" This becomes a research question for the class, and the students look up answers in their resource books and on the Web about plants and seeds. They find out the following information:

- The young plant, or seedling, gets its nutrition from the cotyledons and does not yet need sunlight.
- When the cotyledons are no longer needed, they emerge as seed leaves attached to the stem.
- When the plant begins to develop its first green leaf, it should be placed in a cup or small pot of soil to anchor the roots. At this time the green leaf should be exposed to the sun, because now the plant needs to make food. Green plants use sun, air, and water to make their own food.

My thinking: *At this point, I believe the students still have a long way to go before they have a deep understanding of the science idea that green plants make their own food. What does it mean for a plant to make its own food? What does the food look like? Soon Ms. Fraser begins to address such questions.*

Ms. Fraser introduces the term **photosynthesis** to the group. This is the process, she explains, by which green plants use carbon dioxide from the air and water from the soil, in the presence of sunlight, to manufacture molecules of glucose. Glucose is a simple sugar that the cells of the plant use to make energy

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Taxonomy

By exploring **seed plants**, which scientists call **angiosperms**, Ms. Fraser's students are learning about one major category of plants. Angiosperms produce flowers that form fruits that have seeds. Garden and wild flowers, weeds, grasses, grains, plants that produce vegetables, and shrubs and trees that lose their leaves in autumn are all seed plants.

But why, you may wonder, do we bother to label plants with names like angiosperm? The answer is that classification schemes for living things help us understand and study the life on our planet. These schemes, which are human inventions, allow us to sort, group, and rank the types of life that share the earth with us (Margulis & Schwartz, 1982).

An entire classification system is called a **taxonomy**. The noted biologist and science writer Stephen Jay Gould (1983) remarked that "taxonomies are reflections of human thought; they express our most fundamental concepts about the objects of our universe. Each taxonomy is a theory about the creature that it classifies."

In other words, by creating a taxonomy in which pumpkins and lima beans fall into the same category called angiosperms, we are expressing ideas about those plants' relationships to one another and to other plants as well. Typically, the relationships expressed by today's taxonomies are based on ideas about evolution—how and when particular living things developed their current form.

No taxonomy is absolute. Consider the most basic grouping, the kingdom. In science, a **kingdom** is the largest, most inclusive level of classification of living things. When I was growing up, the living things we learned about were all placed into two kingdoms: the Animal Kingdom and the Plant Kingdom. Now, however, scientists classify living things into five kingdoms. The number changed because scientists have found out much more about what is alive than they knew a few decades ago.

The five kingdoms recognized today are:

Monera (monerans). Single-celled organisms including all types of bacteria.

Protista (protists). Single-celled organisms including algae, amoebas, paramecia, and others.

Fungi. Multicelled organisms such as slime molds, yeasts, and mushrooms.

Plantae (plants). Multicelled organisms that make all their own food through photosynthesis, including mosses, horsetails, ferns, trees, and all seed-bearing plants.

Animalia (animals). Multicelled organisms including plant eaters, meat eaters, and parasites. Animals range from sponges, jellyfish, and earthworms to fish, amphibians, reptiles, birds, and mammals.

so the plant can carry on its functions, including growth. This chemical process, combining materials from the air and soil to produce new ones, takes place at a special site in the cells of the leaf called a chloroplast. The chloroplast contains the substance **chlorophyll**, which helps the process of photosynthesis to occur. Chlorophyll also gives the leaf its green color.

When the plants make their own food, Ms. Fraser continues, they give off extra water vapor and oxygen to their surroundings. This is something we can see, she tells the class. "How can we see it?" many of them want to know.

My thinking: Photosynthesis may be difficult for these students to understand, but by suggesting an observation the students themselves can make, Ms. Fraser helps to tie the idea to their own experience.

Making a Complex Process Visible

Following her guidance, the students place a small green plant (somewhat larger and more robust than their brand-new plants) in a large glass jar. They cover the jar with its lid. After a day or two, they see water vapor droplets appear on the inside of the jar.

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My thinking: I'm pleased that Ms. Fraser is introducing a very complex process at this early grade level. The students now have some prior experience with this idea that they can build on as they mature.

The Teaching Ideas behind These Stories

- In the story of Mr. Bauer's class, we see how simple experiments with seeds can engage students in the mystery of growth and development.
- We also see that edible seeds can represent a challenge for young children. The fact that many foods come from the ground and start as part of a plant is not taken-for-granted knowledge.
- The activity through which Mr. Bauer guides his students has many fine points. It also shows us, however, that even with the best intentions, it is not a good idea to fool students. Instead of trying to sneak in a replacement for a seed that didn't grow, it would have been better for Mr. Bauer to avoid setting up an experience in which students might personalize the experiment's success or failure as their own. Mr. Bauer would have been better advised to use larger cups with two or three seeds. He was lucky that all the other students' seeds germinated.
- Science is about experimenting. Sometimes it works, and sometimes it does not work. There is often much to learn from failed experiments. They provide opportunities to change direction and explore other possibilities. For instance, if some seeds fail to grow, you can ask, "Why do some seeds germinate, while others do not?"
- Notice how, in her class, Ms. Fraser gives her students multiple opportunities for observation. For example, she demonstrates the importance of soaking the beans by asking the students to observe what has happened to the beans she soaked overnight. Hanging the germination bags in the classroom also allows the students many chances to make direct observations. By middle school, when these students begin to study plant cells under a microscope, their observational skills will be well developed, and they will have a good deal of prior knowledge about plants.
- Notice, too, how Ms. Fraser's third graders go beyond examining the seeds and move toward collaborating in the planning of their own investigations. She has structured the activity so they can discuss with their partners, and with other students in the class, the best way to germinate a seed. Each pair of students can make their own plans, carry them out, and determine the results.
- As her students develop questions that cannot be answered through direct observation and experimentation at this stage, notice how Ms. Fraser directs them to resources—in this case, books in the classroom or the Internet. Some schools use science textbooks, which can also serve as resources.
- The entire activity in Ms. Fraser's class, with its multiple spin-offs, takes place over two weeks or more—a significant allotment of time. Later in this chapter, we will see more examples of how science learning requires sustained inquiry over time.
- Even if a science idea is very complex, a demonstration or activity that presents part of it can be useful. By showing her students that a small green plant can release water vapor inside a closed glass jar, Ms. Fraser is leading them toward the beginnings of understanding, and she is helping to make an abstract concept more concrete.

The Science Ideas behind These Stories

- Seeds contain the baby plant or embryo and the food that the embryo needs to begin germinating. This food is contained within the part of the seed called a cotyledon.
- Some seeds do not develop properly, and some do not even have an embryo. Thus, it is always a good idea to plant more than one seed.
- Seeds do not need sunlight when they begin to grow. At first, they live off the stored food in their cotyledons. Once the new plant grows leaves, it needs sunlight to make its own food.
- When seeds sprout, the cotyledons become the first leaves of the baby plant, and they fall off as soon as the plant grows its first adult leaves. Some plants produce seeds with one cotyledon; these plants are

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called **monocots**. Plants that produce seeds with two cotyledons are called **dicots**. Grasses and grains are monocots. Flowers, flowering trees, beans, and vegetable-producing plants are usually dicots. For many seeds, soaking begins the germination process.

- The soil must be firm and porous to support the roots of a seed plant. The soil supplies green plants with an anchor for their roots and space in which to grow.
- Dissolved minerals in the soil make their way to a plant through the water intake of its root system.
- Although the minerals from the soil are important, green plants do not get *food* from the soil. They make their own food through the complex process of photosynthesis. This is a chemical process in which the leaf, aided by its chlorophyll, uses water from the soil and a gas in the air called carbon dioxide to make a simple sugar called glucose and to release another gas, oxygen. The carbon dioxide enters the leaf through openings on its underside called *stomata*. The oxygen gets released into the air through these same stomata.
- Understanding the process of photosynthesis, by which green plants take in carbon dioxide from the atmosphere and release oxygen to the atmosphere, is fundamental to green science. Carbon dioxide is one of several **greenhouse gases**. Greenhouse gases allow sunlight to enter the atmosphere, but when part of that radiation is reflected from the earth's surface in the form of infrared radiation (sometimes called "heat radiation"), the gases absorb this radiation and trap the heat in the atmosphere. Over time, the amount of energy sent from the sun to the earth should be about the same as the amount of energy radiated back into space, leaving the temperature of the earth's surface roughly constant; but when outward radiation is blocked, the earth's surface gradually heats up like a greenhouse. Understanding how green plants use carbon dioxide can provide us with insights into the damaging effects of removing too many trees from the earth's surface. The more trees we remove for various uses, the fewer avenues there are for removing carbon dioxide from the atmosphere.

Connections to the Next Generation Science Standards

- **NGSS DCIs**
  - **1-LS1-1: Information Processing:** Plants respond to external inputs with behaviors that help them survive.
  - **1-LS1-2: Growth and Development of Organisms:** Adult plants and animals can have young.
  - **3-LS1-1: Growth and Development of Organisms:** Reproduction is essential to the continued existence of every kind of organism. Plants and animals have unique and diverse life cycles.
- **NGSS SEPs:** Students were engaged in *asking questions and defining problems*, *planning and carrying out investigations*, *constructing explanations*, and *engaging in argument from evidence*. They *obtained, evaluated, and communicated information*.
- **NGSS CCs:** Students recognized *cause and effect* relationships when they examined plant growth; they were engaged with *structure and function* as they examined the seeds. They considered *scale, proportion, and quantity* as the seeds germinated, and they explored seed to plant as a *pattern*.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- Try planting citrus seeds such as grapefruit or orange seeds. How well do you think they will grow in your own home? Do they surprise you?
- Buy wheat berries (typically found in health-food stores). Fill a shallow pie pan with soil. Sprinkle the wheat berries on the soil and water them well. See what happens.
- What do we mean by saying that green plants make their own food? How is this different from what animals do?
- Since green plants make their own food, what is the plant "food" sold in stores?

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6-4 Studying Plant Life Cycles in Nature

cotyledon
The part of the seed that has food stored in it for the tiny plant. Also called the *seed leaf*.

germination
The process by which a seed sprouts and begins to grow into a new plant.

In the next story, a fifth-grade teacher engages her students in planting a garden in a vacant lot not far from an inner-city school. See how this experience can relate to the story about examining local trees in an urban environment from Chapter 4. In each case, observation has a specific disciplinary context. This story expands students' understanding of the life cycle of plants.

SCIENCE STORY

Planting in a Vacant Lot

In one inner-city community, many of the students walk past an empty lot strewn with garbage on their way to school. Ms. Monteiro, a fifth-grade teacher, notices this, and she thinks about the possibility of planting seeds and nurturing plant growth as both a class activity and a means of community involvement. Recently she has read the book *Seedfolks* by Paul Fleischman (1997), a delightful story of a community of diverse immigrants in Cleveland who contributed their time and energy to convert a vacant lot into a garden.

Inspired by this book, Ms. Monteiro and her class write letters to the local newspaper and to city officials in order to get the trash removed. It takes several months, but eventually the trash is indeed carted away. Now the students visit the lot and claim it for their own.

With the permission of the city, this fifth-grade class turns the vacant lot into a garden. Topsoil is donated by a garden supply store in a neighboring suburb, and the students get to work making the ground ready. They have already noticed how dandelions and crabgrasses grew in this lot despite the trash, so they have high hopes for their own plants. The students do a lot of work preparing the soil and researching the conditions under which their seeds will germinate.

The students have many decisions to make. Some want to plant vegetables; some want to plant flowers. Whenever possible, Ms. Monteiro allows them to make their own choices and select their own seeds. The final choices include lima beans, sunflowers, pumpkins, lentils, marigolds, and snapdragons. By early spring, the students begin sprouting the seeds in containers in the classroom. When the seeds have germinated and have well-formed roots, the students plant them in the ground.

Meanwhile, in their classroom, the students have examined the seeds and the leaves of their sprouting plants. They have studied germination and the role of the soil, water, and sun. They learn that outdoor plants have their own particular growing seasons but that they can simulate some outdoor conditions in the classroom.

Some students who have immigrated from the tropical climates of islands in the Caribbean are disappointed to learn that the harsh winters of their new home will not allow some of their favorite foods to grow. One boy originally wanted an avocado tree in the garden. Instead, he plants an avocado seed in a carefully controlled environment in the classroom (Figure 6.3).

As the season progresses, the students make regular visits to their outdoor garden. In their eyes, nothing has ever been more beautiful than this formerly vacant lot. A sign identifying the class and the teacher stands proudly on the site.

The project is limited by the brevity of spring in this Midwestern city. But before the end of the school year, arrangements are made for the garden to be cared for during the summer by students and community volunteers. In the autumn, when the students return, they plant crocus and tulip bulbs donated by local businesses.

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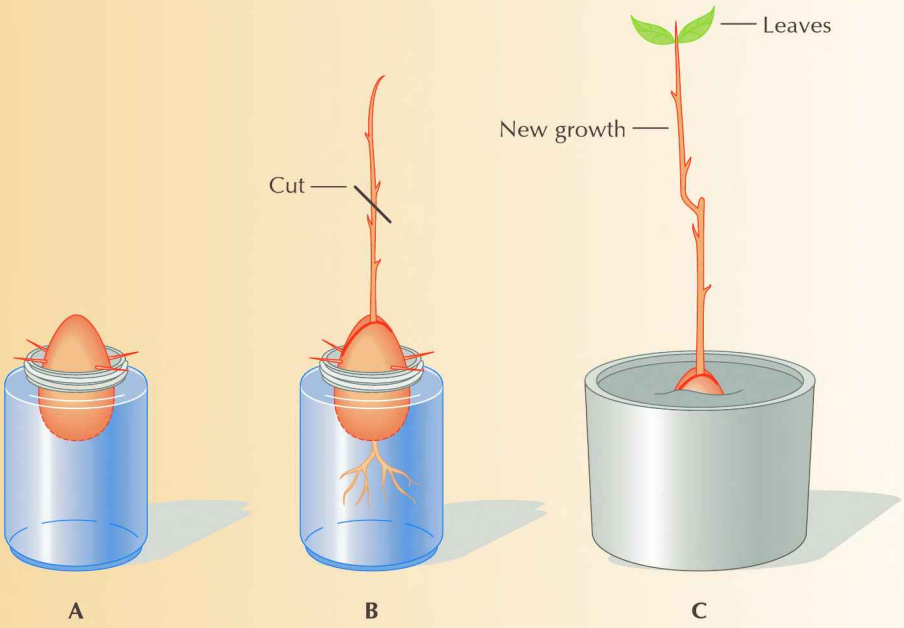

FIGURE 6.3 Steps in planting an avocado pit
(A) After washing the avocado pit and peeling off the skin, place toothpicks in the seed and suspend it in a jar of water, pointed side up. Making sure the bottom of the seed is covered with water, place the jar in a dark place. (B) Wait until roots begin to grow and the stem is about 15 centimeters high. To thicken the roots, cut the stem about halfway up and return the plant to the dark for another few weeks. (C) Finally, when the stem has again grown to about 15 centimeters, place the seedling in a deep pot of soil so the roots are completely covered and the top 2 centimeters of the seed show above the soil. Water the plant well.

6-4a Plant Parts and Plant Function

In the next science story, students are challenged to group plant parts by the function that they serve for the plant. The crosscutting concept of structure and function comes alive in this third-grade class.

SCIENCE STORY

When Is a Vegetable a Fruit?

Ms. Byrne's third-grade class is learning about parts of plants that we can eat. One day she brings in a number of such edible plant parts: apples, oranges, celery, pea pods, lettuce, spinach, tomatoes, red and green peppers, mango, papaya, collard greens, broccoli, carrots, avocado, persimmon, and fennel. (Ms. Byrne knows that her students come from different cultures and that several students have arrived from Central America, so she makes sure to bring foods familiar to these students.)

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After having the students divide into groups, Ms. Byrne invites them to use plastic knives to examine the specimens. "We don't know the names of all these fruits and vegetables," declares one student. "Yeah, I've never seen this before," another chimes in. Ms. Byrne explains that knowing the names wouldn't necessarily mean very much. "If all I knew about you," she says to one student, "was your name, then I wouldn't know very much, would I?"

To guide the students, she offers a suggestion: "We can begin by exploring which of our plant parts have seeds and which do not." The students begin to squeal with delight as they dissect their foods. John shouts, "This one is my favorite," as he holds up an avocado. "What's that?" inquires a classmate.

The students begin to share information about their favorite foods while creating two groups of plants: those with seeds and those without seeds. John holds up the pit of the avocado and explains how to plant it in a pot of soil in order to grow a new plant. Ms. Byrne makes a note to do this in class the next day.

The students then observe the seeds in one pile of foods and the absence of seeds in another pile. Holding up an apple and an orange, Ms. Byrne asks the students what we call these parts of the plant.

"They are fruits," declares Jessica, and everyone agrees.

"Yes, scientists refer to the parts of a plant that hold seeds as the fruit of a plant."

The students are stunned to notice, however, that the tomatoes, red and green peppers, pea pods, avocado, and persimmon are all in the pile with the fruits. "If a tomato is a fruit," asks Ruby, "then what are vegetables?"

Ms. Byrne responds, "What do you think?" She holds up the carrot and asks the students to think about what part of the plant it is. Someone knows it is a root. Others realize that celery is a stem; that broccoli florets are flowers; and that collard greens, lettuce, and spinach are all leaves of the plant.

The students then take turns talking about the fruits or vegetables that they eat at home. Some take pleasure in describing the joys of eating mango or papaya or persimmon. Others explain how fennel or collard greens are prepared in their homes. This leads to a discussion of where the plant is grown, how it is eaten, and what significance, if any, the fruit or vegetable has in particular cultures.

The Teaching Ideas behind These Stories

- In the vacant lot story, we see how nature can present itself in the most unlikely places. Plants break through wherever they can. These unlikely places can become precious resources to the urban teacher with a keen eye.
- The vacant lot story also demonstrates one way to involve the students in the surrounding community and vice versa.
- In the fruits and vegetables story, Ms. Byrne can create meaningful science experiences for her students because she knows who they are, what they eat, and where they come from. The experiences she provides help the students develop their personal knowledge of science.
- The story of Ms. Byrne's class also reminds us of the gifts of diverse student populations and how excited students get when the class curriculum reflects their lived experiences.
- In both stories, the students' ability to construct meaning is strengthened by their interactions as they collaborate with one another. They share knowledge, opinions, and observations.
- In the vacant lot story, the activity takes place over a long period of time—most of the school year and on through the summer into the next school year. This sustained project allows students to develop a deeper, more personal knowledge of the science ideas behind plants.

The Science Ideas behind These Stories

- Fruits and vegetables are edible parts of plants.
- In everyday language, fruits are usually those plant parts that taste sweet, particularly those we get from trees, such as apples, pears, peaches, oranges, and bananas.
- In scientific classification, however, sweetness is not the important factor. A **vegetable** is a root, stem, leaf, or flower of a plant. The **fruit** is the part of the plant that is a container for the seeds. To be even more specific, a fruit is the ripened ovary of a flowering plant.
- Nuts, corn, wheat, tomatoes, peas, beans, cucumbers, pumpkins, and squash are really fruits.

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Connections to the Next Generation Science Standards

- **NGSS DCI: 4-LS1-1: Structure and Function:** Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction.
- **NGSS SEPs:** Students are *engaged in arguing from evidence* and *obtaining, evaluating, and communicating information.*
- **NGSS CCs:** Students were observing *patterns* as they grouped and classified their plant parts. They were engaged with *structure and function* as they examined the role each part plays in the plant's survival.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- What fruits and vegetables do you encounter in your daily life?
- Are there any edible plant parts that you have difficulty labeling as fruit or vegetable? How can you find out the correct classification?
- In a later chapter, we will learn about some students who use fruits and vegetables to make an edible model. What do you think it will be a model of?

6-5 A Classroom Invertebrate

photosynthesis
The process by which green plants use carbon dioxide from the air and water from the soil, in the presence of sunlight, to manufacture molecules of glucose. Glucose is a simple sugar that the cells of the plant then use to make energy for the plant to carry on its functions, including growth.

chlorophyll
The substance in leaves that allows the chemical reaction of photosynthesis to take place and that gives leaves their green color.

angiosperm (seed plant)
A seed plant; one that produces flowers that eventually form fruits with seeds.

taxonomy
An entire classification system, such as the scientific classification of all living things into categories ranging from kingdom to species.

kingdom
The broadest division of classification of living things. There are five kingdoms of living organisms: Animalia, Plantae, Protista, Fungi, and Monera.

Earlier in this chapter, we noticed young students experimenting with seeds. First graders planted them in cups, while third graders explored germination and some of the properties of green plants. Animal life is usually less accessible for classroom projects, and keeping an animal in the classroom often requires some kind of clearance from the school or the district.

An exception to these constraints on using live animals is the earthworm, a wiggly, soft, reddish-brown invertebrate that is slimy to the touch. **Invertebrate** animals have no internal backbone, and their skeleton is usually located on the exterior of the body rather than the interior. Insects, jellyfish, worms, crayfish, and crabs are all invertebrates. **Vertebrate** animals, in contrast, are those with internal backbones, including all fish, amphibians, birds, reptiles, and mammals.

Earthworms, as their name implies, make their home in the soil, and you can tell that your garden is healthy if they are there in abundance. Even urban students encounter earthworms at a nearby park or a local patch of green. Earthworms are also readily available for purchase at a pet store or a bait shop. If you live near grassy fields or have a backyard garden, you can find earthworms after a rainstorm because they like to come to the surface when the ground is wet.

6-4a Observing and Investigating Earthworms

The earthworm has many interesting features to observe (Photo 6.3). Using a magnifying lens, students will see rings, defining the many segments of the worm (Figure 6.4). Earthworms can have up to 170 segments. On the first segment is the mouth and on the last segment is the anus—sort of like the beginning and the end. Watching the earthworms move is fascinating. Circular and long muscles propel the earthworm forward, and tiny hairs or bristles, called *setae*, help it to slow or stop. A thick section of the body, called the *clitellum*, secretes a fluid that the worm uses to make a sac for depositing eggs.

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Monera (monerans)
A kingdom of living things consisting of bacteria, tiny organisms that do not have chlorophyll and cannot make their own food. All bacteria are made up of just one cell. Blue-green algae are also a part of the Monera kingdom.

Protista (protists)
A kingdom of simple organisms, consisting mainly of algae, except for blue-green algae. Other protists are protozoans like the amoeba, paramecium, and euglena.

Fungi
A kingdom of living things containing tiny plantlike organisms. Fungi do not have chlorophyll and cannot make their own food. Fungi include molds, mildews, yeast, and mushrooms.

Fuse/Jupiter Images

PHOTO 6.3 "Gross" or "cool"? The common earthworm is a convenient and fascinating invertebrate for children to study.

> *The plow is one of the most ancient and most valuable of man's inventions; but long before he existed, the land was in fact regularly plowed and still continues to be thus plowed by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organized creatures.*
> —CHARLES DARWIN, 1881

Plantae (plants)
The kingdom of all land plants, that is, multicelled organisms that make all their own food through photosynthesis.

Animalia (animals)
The scientific name for the animal kingdom. It is commonly divided into two broad groups: animals with backbones and animals without backbones.

monocot
A type of seed-producing plant with just one cotyledon or seed leaf—for example, lilies, tulips, irises, onions, and grasses and grains. Also called *monocotyledon plants*.

dicot
Seed-producing plant with two seed leaves, or cotyledons. Dicots include most flowers, vegetable shrubs, bean plants, and flowering trees.

greenhouse gases
Gases that reduce the amount of heat energy (infrared radiation) that is radiated back toward space when the sun's energy enters the atmosphere and strikes the earth. These gases include carbon dioxide, methane,

To house earthworms in your classroom, you can make wormeries from 2-liter plastic soda bottles:

1. The class can collect clean, dry, empty 2-liter plastic bottles. Cut the top from each bottle about 10 centimeters below the neck.
2. At the bottom of each bottle, place a thin layer of gravel. Over that, add a deep layer of soil. Then place a thin band of sand, about 2 centimeters thick, over the soil. These three layers should fill the bottle up to about 5 centimeters below the top. The sand layer will make the earthworm's burrowing more visible.

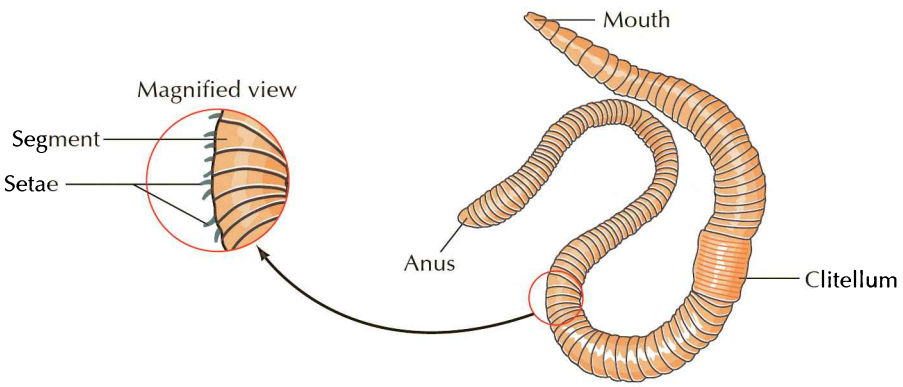

FIGURE 6.4 Parts of the earthworm

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and nitrous oxide. Many greenhouse gases occur naturally, but they may also be produced by industrial processes. Excess greenhouse gases in the atmosphere can cause average temperatures to climb over time.

vegetable
An edible plant part that is the root, stem, leaf, or flower of the plant.

fruit
A ripened ovary of a seed plant; a container for the plant's seeds.

invertebrate
An animal without a backbone. Invertebrates are the most numerous of all animals.

vertebrate
An animal with a backbone. There are five vertebrate groups: fish, amphibians, birds, reptiles, and mammals.

3. The surface of the last layer, the sand, should be covered with dried leaves.
4. Use aluminum foil to make a loose cover for the worm bottle, secured by a rubber band. With a toothpick, poke several holes in the foil cover to let air in.
5. A large piece of black paper should be fastened with tape around the bottle to simulate the darkness underground. Students will remove this paper when they make their observations.
6. No more than three earthworms should be placed in each worm bottle.

Students can explore an earthworm with a magnifying lens and a paper plate. Small spray bottles should be available to gently keep the earthworm moist. To prepare the students to observe the behavior of their earthworms, distribute the magnifying lenses and paper plates beforehand. Each student should receive his or her own earthworm to explore. The students may work in groups of two and compare each other's specimens. Once they begin their observations, you will probably hear exclamations of horror fill the room: "Ewww! Gross! They are so slimy!" The earthworm has no lungs and takes in oxygen through its moist skin. If it dries out, it will suffocate, so its skin has mucus-secreting cells—hence the sliminess. The mucus also helps the earthworms as they burrow down through the soil.

You may want to ask your students, "How can we compare the size of the earthworms with our own size?" By fourth grade, many students can compare the sizes of two objects by using ratios. As your students explore, they will also come up with many fascinating questions of their own, as the following story demonstrates.

SCIENCE STORY

Learning about Earthworms

Ms. Sloane's fourth-grade class has twenty-four students and twenty-four earthworms. Prior to the arrival of the earthworms, Ms. Sloane asked the class to think about what it would be like to be an earthworm. The students were asked to look for information about earthworms in trade books and on the Internet and explore some responses to this question. They worked in assigned pairs and entered responses to the following prompt in their science notebooks:

> What is it like to be an earthworm?

The students' answers included the following:

- *They like the dark.*
- *They are slimy.*
- *They dig deep holes in the ground.*
- *They eat dead leaves and soil.*
- *They can grow a part of their body back if it gets cut off.*
- *They are the world's best gardeners.*

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Ms. Sloane is pleased with the students' responses. They did their research and are now ready to make first-hand observations.

Ms. Sloane explains to the class that after they make observations of their earthworms, they must place the worms in one of the worm bottles that the class has prepared. "Only three earthworms to a bottle," she reminds the students. She asks why they are limiting the number per bottle, and the students respond that the worms need room to burrow. The worm bottle, after all, is a confining space.

Ms. Sloane also explains to the students that they will be observing the earthworms for a few weeks to explore how they tunnel through the soil. After the students compare their observations with their partners', they are required to come up with a testable question about the earthworms, one they can answer through careful observation and experimentation. They are not, however, allowed to cut worms to experiment with regeneration.

Before the class begins to handle the animals, Ms. Sloane points out that working with live specimens is a big responsibility. She invites the students to brainstorm about how they will interact with the earthworms. They come up with a number of rules to write on a piece of poster board, including the following:

- Wash hands and tables thoroughly before and after handling the worms.
- Use rubber gloves when examining the worms.
- Handle the earthworms gently.
- Do not hold them up too high.
- Keep the earthworms moist.
- Keep the soil in the worm bottle wet.
- Be sure the worms have food just below the dried leaves. The food may be small bits of raw potato, raw apple, or dried cereal.
- Do not disturb the worm bottle unnecessarily. Keep the worm bottles covered with black paper between the times of observations.

Questions for Investigations

The students make observations of their earthworms prior to placing them in their worm bottle homes. They are instructed to ask questions, which they can investigate over the coming weeks. Some students wonder what food the worms prefer: dried leaves, apples, potatoes, or cereal. Other students wonder how deep the worms would burrow if they were in potting soil, in sand only, or in a mixture of sand and soil. Still other students wonder if the worms will grow in length over a three-week period.

Setting up the experiments is challenging. Students have to design an investigation that represents a fair test. Like Ms. Parker's students in Chapter 2, the students think about constants and variables—which factors they will keep the same throughout the experiment and which factors they will change. The group exploring the earthworms' preferred food uses two-liter bottle homes with identical soil and moisture composition and varies the food at the top surface of the sand layer, just under the dried leaves. They make observations every two days and record these in their science notebooks. They have also recorded their question and their exact procedure. They indicate how frequently they have to add food for each of the worm bottles they are exploring. In all cases, there are three worms per bottle. Similarly, the group of students exploring which soil allows the earthworms to burrow deepest keeps the moisture and food constant and changes the composition of the soil in each of three bottles.

In all cases, Ms. Sloane asks the students to follow this format for recording their earthworm inquiry:

- What is the research question?
- What is the plan?

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- What is your timeline? How often will you observe?
- Dates and descriptions of observations
- Conclusions:
  - What are your results?
  - Describe the uncertainties. Do you think there were errors in the procedure?
  - Write two new things you learned about earthworms.

By the end of a month, the students begin to produce their own book about earthworms, full of careful drawings, observations, and information drawn from their own research. After some debate about the best title for their book, the students decide to call it *Earthworms—We Can't Live Without Them!*

The Teaching Ideas behind This Story

- Inviting students to examine living things in detail provides them with a fuller understanding of the questions, "What is alive?" What is the connection between structure and function?
- This sort of exploration can take many forms in the classroom. A wise teacher, like Ms. Sloane in this story, creates an environment in which students' own ideas flourish.
- By requiring that the students explore a testable question, Ms. Sloane engages them in the processes of inquiry, helping them to understand how science works.
- Exploring the earthworms in pairs encourages the students to collaborate and share ideas. This points again to one of the key themes from the National Science Education Standards: We learn science by collaboration. This is true because science is, among other things, a social process.
- The theme that science takes time emerges here as well, as it did in both Ms. Fraser's and Ms. Monteiro's classes. Ms. Sloane is generous in her promise of time for studying the worms because she is confident that she can help the students make good use of the time they spend.

The Science Ideas behind This Story

- Earthworms live where there is food, moisture, oxygen, and a favorable temperature (around 50 degrees Fahrenheit).
- Earthworms travel underground by making muscular contractions that alternately shorten and lengthen their bodies.
- In the process of tunneling down through the soil, earthworms digest the leaf litter on the surface and ingest the soil as well. In this way they help to "turn" the soil—bringing down organic matter from the top and mixing it with the soil below. Their excrement, called *castings*, gets deposited on the soil surface and provides nutrients for the soil.
- Earthworms help to increase the amount of air and water that gets into the soil by making their burrows as they move underground. Because they aerate the soil and provide room for roots, they are earth's natural gardeners.

Connections to the Next Generation Science Standards

- **NGSS DCIs**
  - **4-LS1-1: Structure and Function:** Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction.
  - **5-LS2-1: Cycles of Matter and Energy Transfer in Ecosystems:** Matter cycles between the air and the soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases and water from the environment and release waste matter (gas, liquid, or solid) back into the environment.

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- **NGSS SEPs:** Students were *planning and carrying out investigations; engaging in argument from evidence; analyzing and interpreting data;* and *obtaining, evaluating, and communicating information.*
- **NGSS CCs:** *Stability and change* was evident as students examine the changes in their worms' environment. Students examined *structure and function* as earthworm parts were connected to their functions. The earthworm model system under study represented the ways that scientists use *systems and system models* as tools for understanding.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- Could you find an earthworm in your environment?
- What other small invertebrates could you find where you live?
- What other interesting earthworm studies can you think of?
- How would you encourage students to start a campaign called "Dignity for the Lowly Earthworm"?

6-5b Working Together to Conduct Investigations over Time

In this chapter, we have visited several classrooms and noticed different types of explorations with seeds, plants, and small animals. One way in which these stories converge is that they all honor the students' ideas, a theme stressed throughout this book. In particular, the students in this chapter's stories were encouraged to research their own questions, even when that meant looking beyond the classroom to the Internet, in textbooks, in trade books, or down the block in a vacant lot. This is the basis of any true inquiry in science, and it is the way students can develop their own inquiry skills.

You also noticed, no doubt, that many of the experiences described in this chapter were time intensive; that is, the students were given plenty of time to explore their germinating seeds, their earthworms, and their fruits and vegetables. Plants and animals change over time, and in order to develop students' understanding of these living things, we need to encourage them to sustain their investigations over extended periods of time. In fact, you may often want to encourage your students to repeat experiments. This type of repetition is common to scientific research. Sometimes the students' second experience with the investigation helps them notice things they may have missed the first time around.

Following through on science explorations over time is especially important for students in today's culture of "quick and easy." How, you may ask, can you maintain the students' interest in a single investigation that takes days, weeks, or longer? I believe you will find that when you ask your students to brainstorm answers to their questions about their own investigations, they become very interested in pursuing the answers. And as the stories in this chapter have illustrated, new questions often arise as their investigation continues. Sometimes, in fact, students want to research more questions than there will ever be time for in your class.

Part of your role is to guide your students in their understanding of what can be explored through direct experimentation and what may require research from outside sources. You also take the responsibility to point things

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out and ask them to tell you what they have done so far. You guide and monitor and make suggestions. At the beginning of the school year, your students may need a good deal of structure, depending on how much experience they have had in working on their own. As the school year progresses and they get more practice in self-directed activities, they will become more able researchers.

The stories in this chapter have also stressed the collaborative nature of investigations. The students worked in pairs or groups, sharing their ideas. The teachers, too, essentially collaborated in the experiments, providing the topics and the materials but then allowing the students to gain control over their own learning.

Collaboration works best when the exploration is arranged so that each group of students can participate in the efforts and work of *all* their classmates. Often a "reporting out" time becomes the best part of student collaboration. As we will see in Part 3, it is also a wonderful way to assess what students have learned. Remember that as you and your students engage in these collaborative explorations, you should keep asking yourself: "What are the science concepts behind this experience? What am I hoping the students will learn?"

Other than using the Internet for research, the investigations in this chapter were relatively low-tech. Certainly there are ways to integrate more technology into students' explorations of animals and plants, but there is nothing quite like direct interaction with living things. Planting something and watching it grow, observing an organism and creating a temporary habitat for it, asking questions about nature and finding your own answers—these are ways in which scientific study comes alive in the elementary and middle school classroom. If many students are opting out of experience in the outdoors, as research suggests, then as science teachers we should bring the outdoors into the classroom. The natural world is full of wonder and excitement, and we must get our students to touch and feel, smell and squeal, as they use their senses to engage with living things.

As students mature, they are able to plan their own investigations in more detail and manipulate experimental conditions to gather new information. In the next chapter, we will see some fifth- and seventh-grade students exploring concepts related to density.

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CHAPTER 7

Physical Science Explorations: Density and Its Implications

Next Generation Science Standards

- **Crosscutting Concepts:** 1, 2, 3, 4, 5, 6, 7, 8
- **Disciplinary Core Ideas:** 2-PS1-1, 2-PS1-2, 2-PS1-3, 5-PS1-1, 5-PS1-2, 5-PS1-3, MS-ETS1-1, MS-PS1-2, MS-PS1-3
- **Science and Engineering Practices:** 1, 2, 3, 4, 5, 6, 7, 8

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 7-1 Understand the implications of doing floating and sinking activities with young children.
- 7-2 Discuss how increasingly complex ideas can emerge from exploring liquids with fifth graders.
- 7-3 Explore how building science toys can be a design challenge.
- 7-4 Examine how a teacher can further deepen the discourse in a science lesson.
- 7-5 Discuss the role of emerging relevance in the science classroom.
- 7-6 Understand the components of a learning progression.
- 7-7 Analyze the role of mathematical computation in science experiments.

Reflection To Think About:

- Which weighs more: a can of Coke or a can of Diet Coke?
- Where do you float better: on a lake or on an ocean?
- Why are science teachers often on the lookout for unexpected discoveries?
- How do core science concepts from early grades keep popping up again in higher grades?

As students mature, their open-ended science investigations proceed in directions that we cannot always determine in advance. Concept development occurs naturally as students grow and as they respond to their everyday experiences. Some conceptual changes occur as a result of intentional design by the teacher and, as we will see in this chapter, by the learners as well! Sometimes the investigations lead to an unexpected exploration—and new science concepts.

As the simpler concepts addressing a specific science idea gain more complexity and deeper meaning, we can refer to this process as a learning progression. In the stories that follow, consider the levels of understanding of the physical science concept of density. The stories illustrate the ways in which younger and older elementary and middle school students think about the mass and volume of matter.

As the teacher, you will always have specific learning goals in mind for your students. You will also consider the possible directions in which your students may take an exploration. Often, however, the students will surprise you, and the way you deal with the unexpected will have important implications for your students' learning.

In this chapter, we explore a second-grade activity that addresses the basic ideas behind the disciplinary core ideas of weight and volume of matter by exposing students to objects that sink and float. You will see that such early experiences provide students with prior knowledge for their later, more sophisticated applications of the same concept to begin to construct an understanding of density. The more varied and frequent students' manipulative science experiences are in the early grades, the richer will be the prior knowledge and preparation they bring to their investigations in later grades.

The first story examines how second graders explore the concept of sinking and floating in ways that help them make meaning of the properties of objects that float in water. The next story explores the ways in which fifth-grade students examine the properties of liquids and pursue their own questions to higher levels of thinking and problem solving. The teacher is surprised that the students move toward inferences about the idea of density—it is not a topic she has planned to address—but she chooses to nurture their interests and help them expand their own thinking. After seeing how the fifth graders proceed, the second-grade experience seems much simpler in comparison.

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Finally, we revisit these concepts about density in a seventh-grade class, where the students investigate sinking and floating objects with an eye to testing their own theories and actually measuring density. As we explore these stories, think about your own role as a classroom teacher and how you will guide and facilitate experiences that allow students to move beyond the confines of a single experiment.

In this chapter we examine the different levels of understanding that are addressed as students mature. We also use the concept of "density" as a model to explore how teachers can scaffold students' understanding. Look for moments when the teachers do the following:

- Acknowledge the students' ideas and reflect them back to the class.
- Help pull one experience together before going on to the next.
- Provoke students to look further and build on their insights.
- Extend the lesson to pursue the new ideas and questions that arise.
- Encourage students to use science and engineering practices and help them to *ask questions and define problems*; *develop and use models*; *plan and carry out investigations*; *analyze and interpret data*; *use mathematical and computational thinking*; *construct explanations*; *engage in argument from evidence*; and *obtain, evaluate, and communicate information*.

7-1 Floating and Sinking Experiences with Young Students

In the following Science Story, Ms. Sacco explores floating and sinking activities with her second-grade class.

SCIENCE STORY

Floating and Sinking Fruits

It is the week of Halloween, and Ms. Sacco's second-grade classroom is filled with items pertinent to the season, including pumpkins of varying sizes. The students are exploring the properties of pumpkins.

They measure the pumpkins with string, holding the string around the fattest part of each pumpkin and then marking the string to indicate this distance. Then they lay out the string against the calibrated centimeters of a meter stick. With this procedure, they find out how many centimeters around each pumpkin is at its bulging middle. They learn that this measurement is called the *circumference* of the pumpkin, and it may be compared to the equator of the Earth. Ms. Sacco holds up a globe and shows the students the equator.

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The children are excited about the season. They know they are going to open their largest pumpkin and carve a face in it. First, however, Ms. Sacco asks them to make as many observations as possible about this pumpkin, and she lists them on a poster board:

- It is large.
- It is round.
- It is orange.
- It is hard.
- It has no smell.
- It has a stem.
- It has lines on it.
- Its circumference is 60 centimeters.

Ms. Sacco asks, "What do you think will happen if we place our pumpkin in a basin of water?" The children laugh. "It will sink," they reply. "It will make a big splash."

Ms. Sacco takes the class to the large basin in the custodian's work area, and they hover around her as she fills the basin with water. As she places the pumpkin in the water, the children see that it bobs and floats! Squeals of surprise and chatter ring out as they walk back to their classroom.

The students do not know why the pumpkin floats. Ms. Sacco states, "Let's open the pumpkin, explore its insides, and do some more experiments to solve our mystery." She cuts out a lid around the stem of the pumpkin, and the children look inside. They see a large cavity and, within it, the pulp—the seeds and mushy, moist connecting threads. The pumpkin has a smell when it is opened.

"What else is in there?" Ms. Sacco asks.

"Nothing," the children reply.

The next day, Ms. Sacco brings grapes, oranges, apples, grapefruit, and a green pepper to class. "In what ways are these foods all the same?" Ms. Sacco asks. The second graders respond:

- They are sort of round.
- You can eat them.
- They have skin.
- They all come from plants.

Then the students use a large basin of water to explore whether these items will sink or float. They are shocked to find that only the grape sinks. All the other foods float. Michael wonders why a little grape sinks, but a great big pumpkin floats. It is time to do more investigating.

Ms. Sacco peels the orange and the grapefruit. Now they both sink!

The children explore the skins of both these fruits with a magnifying lens. When they hold the skin up to the light, they notice spaces. "What do you think is in these spaces?" Ms. Sacco asks. Some students say "nothing"; others say "air." She asks them to study the apple fruit itself to see if they can notice spaces in the fleshy part of the apple.

Ms. Sacco invites them to look for what they think might be air spaces in the other fruits. The students find that the floating apples have spaces in the center cavities where the seeds rest. The green pepper and the pumpkin have large empty spaces inside them. The orange has the spaces in its peel. "The orange peel was the life jacket for the orange," Roselia says, and the other students laugh.

Ms. Sacco's thinking: *In an earlier lesson on states of matter, the students explored plastic bags with air inside them. Still, Ms. Sacco has noticed that many students are reluctant to acknowledge that air is inside the spaces in the foods. She is hoping to guide them to this idea. She also hopes that the students will notice that the size of the fruit cannot tell them whether it will sink or float in water. Size (or volume, as it is later called) is less important than what is inside the object.*

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Michael Newman/PhotoEdit

PHOTO 7.1 Which fruits and toys float? Which sink? As they conduct their experiment, these students begin to develop prior knowledge for developing future ideas about density.

To pull the lesson together, Ms. Sacco invites the students to think about what makes some fruits float and others sink (see Photo 7.1). She distributes grapes and magnifying lenses, and the children cut the grapes in half with plastic knives. They observe that there seem to be no open spaces inside a grape. That is why it sinks, they decide. They conclude that a fruit probably will float if there are open spaces inside it.

The Teaching Ideas behind This Story

- To help the children make connections between science and their world, Ms. Sacco is using seasonally relevant materials to explore nature.
- Notice how she challenges the students to draw comparisons and consider properties of the various fruits. She is bringing out their prior knowledge about fruits.
- Ms. Sacco makes connections between the pumpkin and our planet, paving the way for the notion that different objects can be used as models for the earth (see Chapter 8).
- The students use mathematical skills when they measure the circumference of the pumpkin.
- When the students do not know why the pumpkin floats, Ms. Sacco does not tell them. She sanctions the question and gives the students confidence to believe that they will find the answer. She then provides additional experiences that help them do so. Ms. Sacco avoids emphasizing that "air" is inside the fruits that float. Ms. Sacco's students found the evidence to support their tentative explanation for why some fruits float in water.

The Science Ideas behind This Story

- Some fruits float in water because they have air inside them. The air decreases the overall density of the fruit, making it less dense than water. Apples float even without their core because they are about 75 percent water and 20 percent air, and their average density is less than the density of water.
- Objects with a density less than the average density of water float on water. The average density of water is 1 gram per cubic centimeter. This means that 1 cubic centimeter of water (equal to a milliliter of water) has a mass of 1 gram.

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Connections to the Next Generation Science Stories

- **NGSS DCIs: 2-PS1.A:**
  - **2-PS1-1: Structure and Properties of Matter:** Matter can be described and classified by its observable properties.
  - **2-PS1-2 and 2-PS1-3: Structure and Properties of Matter:** Different properties are suited to different purposes.
- **NGSS SEPs:** Students were *planning and carrying out investigations; analyzing and interpreting data;* and *constructing explanations and designing solutions.*
- **NGSS CCs:** Students sought *patterns* in the materials that floated and those that did not; they examined the *cause and effect* of these observable properties.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- If iron has a density of 7.8 grams per cubic centimeter, why do steel ships float?
- What is the ratio between the grape's mass and volume? Greater than 1? Less than 1?
- What other common materials could children use to do the sink-or-float test?

7-2 Older Students Explore the Differing Density of Liquids

In the next science story, a fifth-grade teacher engages her students in a physical science lesson that also explores sinking and floating, but this time *all* the materials are liquids. Notice how one thing leads to another and the students explore ever more complex concepts. This leads to an engineering challenge as students extend their learning.

SCIENCE STORY

Looking at Liquids

Ms. Drescher's fifth-grade class is in a small, urban community thirty-five miles north of a major metropolis. The students are from working-class and middle-class families with a diverse cross-section of ethnicities. Many of the students are immigrants and are struggling with English-language proficiency. Ms. Drescher arranges the students in heterogeneous groups, mixed by race, ability, gender, and ethnicity. A spirit of cooperation pervades her classroom, and all the students are willing to contribute to investigations because they know they will have the opportunity to explore their own ideas.

The students are working on a physical science unit, studying the properties of liquids. They have learned that many kinds of liquids have several properties in common. As the students have already seen, it is often possible to notice differences among liquids as well. Today, they are going to investigate the properties of yellow corn oil, clear corn syrup, and water to which blue food coloring has been added.

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When the students return to their room after lunch, they find clear plastic cups and bottles containing the three liquids. The blue-colored water is labeled as such. The labels on the bottles of corn syrup and corn oil are also in full view, and Ms. Drescher asks the students, "Where do you usually find these items?"

The students respond with their own experiences of using corn oil and corn syrup, or watching others use them, to cook. Most of these students have seen corn oil used in the preparation of fried foods or in salad dressings. One student's family prepares plantains with corn oil. Only a few students have seen corn syrup before. A couple of students know it is used to make candies, and one child's family uses it to make pecan pie. Some students have had experiences with food coloring for dyeing Easter eggs. Ms. Drescher shows the students how the blue food coloring mixes with water.

Ms. Drescher's thinking: *Ms. Drescher is eager to use materials that both work in the investigation and relate to the students' personal experiences. To establish the personal connections, she encourages a discussion of what the students already know about these liquids. She is accessing their prior knowledge.*

Working in groups of three, the students examine cups of the three liquids (Photo 7.2). They have been asked to measure 150 milliliters of each liquid by using a graduated cylinder. "What are we keeping the *same* about these liquids?" Ms. Drescher asks. Some children respond, "The same amount." Ms. Drescher looks at the class as a whole and says, "We know what scientists mean by 'the same amount.' Let's use the exact term." Several students then respond, "Volume."

Ms. Drescher's thinking: *Ms. Drescher is sure that the students know the meaning of volume, but she wants them to practice using the term.*

She holds up equal volumes of the three liquids and asks, "In what ways are these liquids the same? In what ways are they different?" The students share observations about color, thickness, and transparency. Marisa offers, "You can see through the blue water and the corn oil, but it is harder to see through the corn syrup."

Another student notices that the cup of corn syrup feels heavier than the other cups. "Good observation," Ms. Drescher replies. "How can we prove that it is really heavier?" The students reply that they could weigh the cups. Taking out their digital gram scales, the students observe that 150 milliliters (ml) of corn syrup weighs more than 150 ml of blue water or 150 ml of corn oil.

Fuse/Jupiter Images

PHOTO 7.2 What will happen when the three different liquids are mixed? The students have measured the volume of each liquid, and they will carefully observe and record the results.

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Ms. Drescher invites the students to think about what would happen if they combined the three liquids in one container. The students spend some time writing their ideas in their science notebooks. "To make a fair test," she asks, "what must we keep the same?" "The volume," the students respond. "Yes," replies Ms. Drescher, and she explains how important it is to keep the volume the same when combining the liquids.

Ms. Drescher's thinking: *Ms. Drescher wants the students to see that "how much" you have of something can influence how it behaves with another substance. She knows that "doing science" means measuring and manipulating, but it also means planning investigations and thinking about procedures.*

Ms. Drescher continues, "When we keep the amount or volume the same, we can honestly observe what happens when the liquids mix together. We can refer to the volume of the liquids as our *constant*, the property we keep the same. Then what is it that we are changing?"

The students respond that the liquids are different even though the volumes are the same. Ms. Drescher reminds the students that the things that change in an experiment are called the *variables*.

One student asks, "Which liquid should we pour first?" Ms. Drescher responds by saying, "That is your choice. Plan your investigation, and decide what volumes you will use."

Working in their groups, the students think about what will happen when the three liquids combine. They have a total of 150 ml of each liquid and lots of empty plastic cups. Some students think the corn oil will form a middle layer and the corn syrup will sink to the bottom; other groups predict that the oil will sink to the bottom. Some think the liquids will change as they mix together. All the students become involved in sharing their ideas and planning their investigations.

Ms. Drescher's thinking: *Because she wants the students to make choices and get practice with planning investigations, Ms. Drescher does not provide lockstep directions. She is interested in seeing what variables they will use and which properties they will keep constant.*

As it turns out, all the groups keep the volume of the three liquids the same by using the graduated cylinders. But the other procedures differ from group to group. Regardless of the methods they use, all of the students are surprised when they combine their three liquids. "Oohs" and "ahs" can be heard as the syrup falls to the bottom, the oil rises to the top, and the blue water becomes the center layer.

Many students are particularly surprised about the corn oil, and others are surprised that the results are the same regardless of the procedure. Ms. Drescher tells the students that they can spend the entire afternoon on their explorations. They write the results in their science notebooks. Some students also draw pictures of what they have observed.

Ms. Drescher's thinking: *Ms. Drescher knew the students would need time to explore the liquids, so she planned the investigation on a day when she was certain that there would be no interruptions.*

After a time, Ms. Drescher asks the students to sum up what they have found out as a result of their explorations. The students offer ideas, such as, "Some liquids float or sink in water." On a large poster pad at the front of the room, Ms. Drescher records their ideas, including the following comments:

> The liquids were different colors and different thicknesses.
>
> The oil and water layers are clear, and the syrup layer is only partly clear.
>
> The syrup layer poured more slowly than the other layers.
>
> The oil layer feels greasy.

"Well," Ms. Drescher continues, "let's reflect on what happened when you used the same amount of each liquid and weighed the liquids. Which was heaviest? Lightest?"

The students explain that the corn syrup was the heaviest and the corn oil the lightest. "Why do you think," she persists, "the corn syrup is always the heaviest?" The students reason that the corn syrup must have more "stuff" in it than either the water or the corn oil.

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One student asks, "Can we do this again, only this time keep the *weight* of the liquids the same?" Noticing that the class seems enthusiastic about weight being the new constant, Ms. Drescher says, "Sure." She reminds the students that now that weight is their constant, they need to use carefully read the numbers on their digital gram scales.

As students begin to weigh their samples, they notice that the oil and water take up much more space than the syrup does for a given weight. That is because the corn syrup is so heavy; a little bit of it weighs the same as lots of corn oil or water. In other words, the students notice that the corn syrup has the smallest *volume* when the weights of the three liquids are the same. They wonder if it will still sink to the bottom even when there is so little of it.

The students perform the investigation and—yes—the corn syrup always falls to the bottom, even though it has the smallest volume. They do not know why this has happened, and they turn to Ms. Drescher for help. "Remember, we said that the corn syrup sank to the bottom because it had more 'stuff'? Well," she says, "you have discovered another property of matter—the more 'stuff' in a substance, the *denser* it is."

"*Density*," she goes on, "is how closely packed together the particles are." Some students then reason that the oil floats on water because it is not as dense as water and the water floats on the syrup because it is not as dense as the syrup. They are catching on to the idea that densities remain the same regardless of mass or volume.

Ms. Drescher's thinking: *The idea of density was not in Ms. Drescher's plans for this experiment; she would have been content for the students to observe differences in weight among the liquids, along with the other properties they have already noticed. But since the students wanted to explore the relationship between volume and weight, she decided to welcome this unexpected outcome of their curiosity and expand on it.*

7-3 The Design Challenge of Building Science Toys

In the following story, we observe Ms. Drescher continue density explorations by building science toys to illustrate density.

SCIENCE STORY

The Next Day: Building Science Toys to Illustrate Density: A Design Challenge

The next day Ms. Drescher brings a number of decorative liquid-display toys to class—items that use liquids of different densities and colors to create movement and attractive illusions. You have probably seen these objects in stores. The students are surprised to learn that the liquids in these toys resemble the ones they have been working with. "That one looks like corn syrup and water," one student remarks.

As you will see, students use their understanding of liquids at different densities to design and construct their own decorative displays. The concept of design challenges is inherent to engineering practices. We will examine design challenges further in Chapter 11.

Ms. Drescher then gently heats some corn oil by placing it in a heat-resistant glass pot on a warmer plate. She adds several drops of red food coloring, and the red drops seem to dance around in the warmed oil. "That looks like a lava lamp," one student says. Suddenly the entire class begins to guess the types of liquids contained in the other decorative objects.

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Ms. Drescher then sets out for them a variety of clear plastic cups, resealable plastic bags, glues, tapes, food coloring, and liquids. "Suppose you wanted to create your own science toy with these materials. What kinds of designs do you think you could make?" she asks. The students are excited at the possibilities, and Ms. Drescher asks them to work in their groups to develop their plans. "How will you create your own science toy?" she encourages them. "What liquids will you try? What volumes will you use? What do you want your toy to do?"

Each group is given time to explore ideas and plan a procedure. The students discuss their ideas—both scientific and aesthetic—with enthusiasm. Before the groups can begin building their toys, however, Ms. Drescher must approve their designs.

Ms. Drescher's thinking: *While giving the students the freedom to make their own plans, Ms. Drescher wants to be sure they are designing toys that can indeed be built with these materials and that the procedures are safe. I am pleased that she checks the students' plans before they start construction.*

Using the plastic cups and bags, and working in their groups of three, the students create their own science toys. With their understanding of which liquids sink or float in water, they can create their own designs. Using tape and glue to fasten cups and bags together, they even have liquids flowing from one container to another (see Figure 7.1 for an example).

The Teaching Ideas behind This Story

- Notice how Ms. Drescher prompts the students to make connections to their own lived experiences.
- To honor their thinking and encourage their experimentation, Ms. Drescher allows the students to repeat the experiment using mass as their constant. When their exploration leads toward a new concept, she revises her plans and brings in new materials so they can extend their investigation.
- The activities in which Ms. Drescher's students engage are pivotal to the science lesson, but they are not the entire lesson. She also provides students with opportunities to reflect on what they have discovered, talk about their ideas, and expand on their science experience.

The Science Ideas behind This Story

- Remember our earlier stories about solids, liquids, and gases. In Ms. Drescher's class, the students are delving deeper into the category of liquids and realizing that substances in this category can be very different from one another.
- By fifth grade, the basic questions of what we keep the same and what we change become, "What are our constants; what are our variables?"
- A **graduated cylinder**, as we saw in an earlier chapter, is a scientific measuring cup. It is a glass or plastic cylinder that is calibrated in milliliters for liquid volume—a handy tool for the classroom.

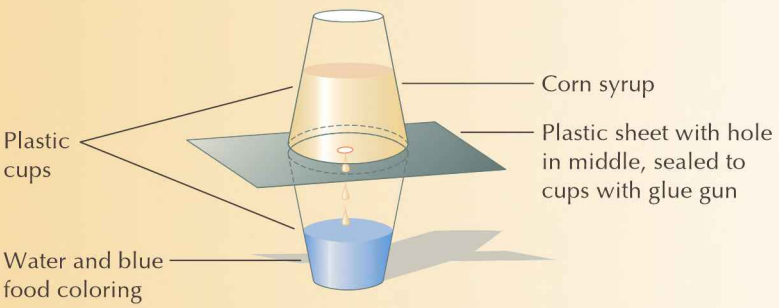

FIGURE 7.1 A simple science toy using clear corn syrup and water tinted with blue food coloring
As the corn syrup drips into the blue water, it settles to the bottom. Turning the cups over begins the process again, so the syrup falls through the water to the bottom cup.

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- **Volume** is the amount of space an object takes up. Liquid volume is measured in milliliters and liters, and solid volume is measured in cubic centimeters (cm^3) and cubic meters (m^3). When we refer to the *size* of an object, we usually mean its volume.
- As we saw in an earlier chapter, **mass** refers to the amount of matter in an object. Students often determine mass in grams by using a digital gram scale. Classes may also use the double-pan balances mentioned earlier in this book: One pan holds the object while calibrated gram weights are placed on the other pan. The digital scale provides more accuracy. *Note at this grade level, mass and weight are not distinguished and density is not intended as an identifiable property. Density emerged here as a consequence of students probing further.
- **Density** is mathematically defined as the mass of an object divided by its volume. It is expressed numerically in grams per cubic centimeter (g/cm^3). You can think of density as how closely packed together the particles are or how many particles can fit into a given amount of space.
- A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample. A mixture of substances often can be separated into the original substances using one or more of the characteristic properties.
- A substance's mass or volume may vary, but the density of that particular substance—the relationship or ratio between its mass and volume—is always constant. The densities of some common materials are listed in Table 7.1.
- The concept of density is complex because it relates to two factors in a given material: its weight *as compared to* its volume. Comparing two variables requires careful planning and frequent measurement.

TABLE 7.1 Densities of Some Common Materials

Material	Density (grams/cubic centimeter)
Cork	0.2
Wood (elm)	0.8
Alcohol	0.8
Olive oil	0.9
Water	1.0
Quartz	2.6
Aluminum	2.7
Iron	7.8
Nickel	8.9
Silver	10.5
Gold	19.3

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Connections to the Next Generation Science Standards

- **NGSS DCIs:**
  - **5-PS1-3: Structure and Properties of Matter:** Measurements of a variety of properties can be used to identify materials. (Boundary: At this grade level, mass and weight are not distinguished.)
  - **MS-ETS1-1: Defining and Delimiting Engineering Problems:** The more precisely a design task's criteria and constraints can be defined, the more likely it is the designed solution will be successful.
- **NGSS SEPs:** Students are *planning and carrying out investigations*. They make measurements and observations to produce data that serve as the basis of evidence for a phenomenon. They are *analyzing and interpreting data* and *using mathematics and computational thinking*. Students *are obtaining, evaluating, and communicating information*. They are also *developing and using models* as they design their toys.
- **NGSS CCs:** Students examine *cause and effect* relationships and *scale, proportion, and quantity* as they examine using standard units to measure and describe physical quantities such as weight and volume.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- How does Ms. Drescher create an atmosphere of trust in her classroom?
- Think about the densities of some other common liquids: for instance, dish soap, red wine, milk, engine oil, olive oil, and house paint. How would they compare in density to corn oil and corn syrup?

7-4 Levels of Understanding: A Further Exploration

In the following story, we observe Ms. Drescher continue density explorations with commonly recognized materials. She is building on the students' interests in these investigations.

SCIENCE STORY

Delving Deeper Into Sinking and Floating

After observing her class pursue the idea of density, Ms. Drescher decides to carry the subject further. A few days later she brings in two soda cans, both unopened. One is Coca-Cola and the other is Diet Coke. She also has a large, deep, wide-mouthed jar, which is more than half filled with water. "We're going to see what happens when we place these soda cans in the deep jar of water," she tells the class. But before performing the experiment, she asks the students to make predictions.

"They'll both sink. Soda cans are heavy," says Tiffany.

"They'll float," offers Justin, "because they have air bubbles inside of them." Some students think the Diet Coke will sink and the regular Coke will float. Others believe the Diet Coke will float because it is "diet." They cannot tell just by holding the two cans of soda which one, if either, will float in water.

After everyone has had a chance to think and predict, Ms. Drescher sets the cans in the water. The Diet Coke floats, and the regular Coke sinks.

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The students try the experiment several ways—they place the soda cans in the water in different order, on their sides, and upside down—but always with the same results. Ms. Drescher asks them to make further observations about the cans. They weigh the cans on double-pan balances as well as on their digital scales and examine the data on the can labels. Here are some of their observations and inferences:

- The cans have the same volume: 335 milliliters.
- The Coke can weighs more than the Diet Coke can.
- The Coke has greater *density* than the Diet Coke—that is why it sank.
- The Coke has 39 grams of sugar in it. The Diet Coke has no sugar in it.

The students want to know if the same thing would happen with other sugared and diet soft drinks. Ms. Drescher encourages them to bring in other soda cans and find out.

The Floating Egg

The following week, Ms. Drescher brings a number of hard-boiled eggs to school along with plastic spoons and containers of salt. She invites the students to explore what happens when they place a hardboiled egg in a clear plastic cup that is three-quarters filled with water.

They try the procedure. "It sinks," one student quickly points out.

This school is not far from the Atlantic Ocean, and Ms. Drescher is confident that students have had experience with salt water. "Let's see what happens to our egg," she says, "when we slowly add salt to the water and stir it to help it dissolve."

The students, working in pairs, slowly add the salt to their cups of water, first one teaspoon, then another. By the third teaspoon, the egg begins to rise; by the fifth teaspoon, it is floating on the water.

"Okay," Ms. Drescher says, "let's talk about this. What's going on here? What is our constant?"

The students respond, "The egg."

"What is our variable?"

They call out, "The amount of salt in the water."

Ms. Drescher continues, "Okay, what did you notice?" The students start talking at once. Ms. Drescher lists their comments on the poster pad in front of the room:

- The more salt in the water, the better the egg floats.
- The salt makes the water heavier.
- Salt water helps you float better—that is why it is easier to float in the ocean than in a swimming pool.
- The salt water is denser than the water from the tap.
- The students reason that the salt dissolved in the tap water and gave the same amount of water many more particles. This made the water denser. The egg then was able to float on a liquid that was denser than the original tap water.

One student asks, "Could the egg float on the corn syrup?"

"What do you think?" Ms. Drescher responds.

"Let's try it!" the students exclaim.

And they do. What do you think they discover?

The Teaching Ideas behind This Story

- Ms. Drescher keeps returning to the concept of density, offering the students different ways to conceptualize it and see what it means in practice. This enables the students to apply the concept to different contexts.
- The students are engaged with everyday materials: water, soda, eggs, and salt. Many students will consider trying these investigations at home.

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The Science Ideas behind This Story

- It takes fewer grams of artificial sweetener to produce the same taste as 39 grams of sugar. That is why the mass of the Coke is greater than the mass of the Diet Coke.
- When salt dissolves in water, the salt molecules separate or dissociate into charged atoms called **ions**. These ions fit between the molecules of water and make the same volume of water contain a larger number of particles. This increases the mass of the water but does not affect its volume. Salt water, therefore, has a greater density than freshwater or tap water.
- Water exerts a lifting force on objects. This lifting force is called **buoyancy**. All objects appear to be lighter in water because of the buoyancy of water. Salt water exerts a greater lifting force than tap water does.

Connections to the Next Generation Science Standards

- **NGSS DCIs**
  - **5-PS1-1: Structure and Properties of Matter:** A model that shows gases are made from matter particles that are too small to see and that are moving freely around in space can explain many observations.
  - **5-PS1-2: Structure and Properties of Matter:** The weight of matter is conserved even when it changes form, even in transitions in which it seems to vanish.
  - **5-PS1-3: Structure and Properties of Matter:** Measurements of a variety of properties can be used to identify materials.
- **NGSS SEPs:** Students are *analyzing and interpreting data* and *engaging in argument from evidence*. They are *obtaining, evaluating, and communicating information*.
- **NGSS CCs:** Students are testing *cause and effect* relationships and examining *scale, proportion, and quantity*.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- What do you think it would be like to learn science with Ms. Drescher?
- What is the actual numerical density of pure water? Salt water?
- What other foods or everyday materials would make good models of materials with different densities?

7-5 Extending Curriculum: Taking Advantage of Emerging Relevance

graduated cylinder
A device used for measuring liquid volume. In essence, it is a scientific measuring cup—a glass or plastic cylinder calibrated in milliliters.

You may be wondering what prompted Ms. Drescher to extend the unit on liquids to such a degree. She not only seizes on the idea of density when the students bring it up, she carries on with it for days afterward. She offers students multiple ways of approaching the idea, repetitions with variation, and new applications. We've seen this process in earlier chapters, but Ms. Drescher is a particularly powerful example of it. She has made an important pedagogical decision, electing to extend the unit in a direction where the students' natural curiosities are leading them. Clearly, Ms. Drescher works in a school environment that encourages curriculum extension. As well, the students feel valued because their plans become central to their science lessons for several days.

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> *Don't be frightened off by complex questions. Take them apart and explore them.*
> —Eleanor Duckworth (1991)

volume
The amount of space an object takes up. Liquid volume is typically measured in milliliters and liters; solid volume, in cubic centimeters and cubic meters. When we refer to the *size* of an object, we usually mean its volume.

mass
The amount of matter that is in an object, typically measured in grams and kilograms.

density
Mathematically defined as the mass of an object divided by its volume (expressed numerically in grams per cubic centimeter). Roughly, density can be conceived as how closely packed together the particles of an object are or as the relative number of particles that can fit into a given amount of space.

ion
A charged atom.

buoyancy
The lifting force that water exerts on objects. All objects appear to be lighter in water because of the buoyancy of water.

emerging relevance
A perception by students that questions or ideas arising from an investigation have personal significance to them. The key part of this concept is that certain matters become relevant to students as they engage in learning activities. By helping them explore these emerging questions and ideas, teachers can help students construct their own meaning.

We know that when students work on a science problem that has "emerging relevance" to them (Brooks & Brooks, 2001), they have a vested interest in solving the problem and a personal commitment to making sense of the solution. The term **emerging relevance** reminds us that relevance can *emerge* through teacher mediation, as it did in Ms. Drescher's class. It does not have to be preexisting. What is clear is that the *students* must see the problem as relevant. You will know when questions or ideas of emerging relevance appear in your own classroom. The key is to start with science problems that connect in some way to the students' lived experiences. These problems then become points of departure for other questions and other problems.

Usually complex problems, such as the layering of three liquids in Ms. Drescher's class, pose further questions to explore as students delve for deeper meaning. Remember, oversimplification is not in the students' best interests. In fact, it often leaves them feeling more confused. So don't be intimidated by complex questions. Take them apart, explore them with the students, and guide the students to consider possible experiments. If Ms. Drescher had not continued the class's explorations of the three liquids, a complex concept like density would have been lost to her fifth graders at a time when it was relevant to their explorations.

Your decision to pursue emerging problems should be based on several factors:

- The availability of materials.
- The relevance of the emerging problem to the overall objectives of your science teaching.
- The ways in which the students see the exploration as relevant to *them*.
- What you have learned about your students' facility at pursuing independent investigations.
- Your own belief that this extension will strengthen students' understanding of the natural world.

As a general rule, it is a good idea to allow more time for a science lesson than you may initially think it requires. The process of exploration takes time, and the follow-up experiences take time as well. Also, make sure that your science experiences involve inexpensive materials that are easily accessible.

In the next story, we visit a second-grade class in the same school district as Ms. Drescher's class. Notice how early ideas about size and materials influence the class discussion. As you read, think about how an experience like this in a second-grade class relates to later activities, like the ones we saw in Ms. Drescher's fifth-grade class.

7-6 Looking Ahead at Deepening Levels of Understanding

> *The more we help children to have their wonderful ideas and to feel good about themselves for having them, the more likely it is that they will some day happen upon wonderful ideas that no one else has happened upon before.*
> —Eleanor Duckworth (2006)

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Far from being a neat, linear process, the construction of new ideas is based on recursively visiting and revisiting prior conceptions, altering our views based on new experiences, reflecting on those views in peer groups, and then, sometimes, formulating a new idea. For this reason, what takes place in Ms. Sacco's class has important implications for what Ms. Drescher's students can learn from the experiences in their class. That is, if Ms. Drescher's students have had prior experiences like those provided by Ms. Sacco, they will be better prepared to understand concepts like volume and density. They can use that prior knowledge to build their new, more complicated ideas.

The children in Ms. Sacco's class believe that the large pumpkin will sink. They find out that that belief is not accurate, and they explore further. This work leads to a partial understanding that the materials inside an object determine one of its properties. They begin to understand that some objects have less "space" inside them than others, and this property can be more important, for some purposes, than the object's size. Ms. Sacco's students are approaching one conception of density—how closely packed the particles are. By the time they have a full-fledged lesson on density, in Ms. Drescher's class or elsewhere, they will be ready for it.

spiraling of curriculum
Engaging students in the same topic of study at different grade levels, so that the topic is explored at greater depth in later grades.

learning progression
In science, the sequence of ever-deepening concepts that result in the understanding of a core scientific idea that is basic to explaining how the natural world works. They are based in research on how people learn.

Most science curricula are constructed so that science topics, and the core concepts associated with them, pop up repeatedly in different grades. This **spiraling of curriculum**, as it has been called (Bruner, 1960), is one way to develop depth of understanding of a topic. This does not mean, of course, that students engage in the same activity over and over. Rather, as they mature, they build on earlier science experiences and develop a greater depth of understanding. These deepening levels of understanding are often called a **learning progression**.

7-7 Using Mathematics and Computational Thinking

Now let's skip ahead to seventh grade to see how the topic of density comes up again when students are old enough to conduct more sophisticated measurements and experiments.

SCIENCE STORY

Apples, Potatoes, and Density

Students in Mr. Hutcheon's seventh-grade class in Lakeville Middle School in the Pacific Northwest address topics in life science, physical science, and earth science. In physical science, the local syllabus calls for the students to explore characteristic properties of matter, like density, boiling point, and solubility. Mr. Hutcheon decides to approach the idea of density through a sinking and floating exploration that engages students in testing some of their own theories about why objects sink or float. To prepare for this unit, Mr. Hutcheon has done extensive research on sinking and floating, and he asks me to visit and observe the process in which he is about to engage his students.

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For the first exploration, Mr. Hutcheon gathers five sets of the following floaters and nonfloaters:

- Two different sizes of corks
- A ball of Plasticine about 3 cm in diameter
- A thick, waxy candle
- A stick of chalk
- A block of wood 4 cm × 7 cm × 2 cm
- A marble
- A coin
- An apple
- A potato

Each set of materials sits inside a plastic basin. Also available for supervised use are plastic knives and vegetable peelers.

Mr. Hutcheon introduces the unit to the class using a 4,000 ml beaker of water, a grapefruit, and a grape. As the students watch, he invites them to think about what happens when an object sinks and when an object floats. The students quickly respond that an object goes to the bottom when it sinks and stays on top when it floats. Class predictions about the grape and grapefruit are mixed; about half the students predict that the grapefruit will sink and the grape float. They are delighted to see that the reverse happens, and they want to know why. Mr. Hutcheon explains that "we are going to make observations of several objects in water and try to come to our own understandings about why some things float and others sink, but, first, let's define what we mean by sinking and floating."

Mr. Hutcheon's thinking: *Floating and sinking are commonly used terms, but scientists have their own meanings for them, and they are not quite as simple as the students have suggested.*

Mr. Hutcheon draws several diagrams of objects at different levels on and under the water. He then asks the students to comment on them. The first is a picture of an object sitting on top of the water, held up by surface tension, like a leaf or a water strider. Some students think it is "just sitting" on the water, but others declare that it is actually floating. Next is a drawing of an object that is partially on top and partially under the water. Some students say, "The top part is floating and the bottom part is sinking." "Actually," Mr. Hutcheon offers, "scientists would definitely call this floating." In the next drawing the object is immersed in the water but freely suspended, like a fish. Some students say, "No, it is under the water, so it is sinking." Mr. Hutcheon clarifies by saying, "This is another form of floating. Floating in a liquid refers to objects that are partly or wholly immersed in the liquid, as long as they are not touching the bottom. The object can be moving or stationary. Let's think about objects as floating or not floating."

The bell rings, and Mr. Hutcheon asks the students to think about whether an iceberg is floating and how they would define a "sinker." The students move on to the next class.

My thinking: *I notice how engaged the students became in what, at first, seemed like a simple topic and how quickly the science period went by.*

The following day, Mr. Hutcheon has the class for two periods. The students are now prepared to discuss what it means for something to sink. They have found out that an iceberg floats. Now Mr. Hutcheon draws other objects on the board. The first is a ship, lower in the water than usual, and the students think it is sinking. "It may be," said Mr. Hutcheon, "but in this picture it is still floating. Try to remember," he adds, "that if the object is in any way supported by the water, it is floating." In the next picture, there is an object that is moving downward through the liquid and landing on the bottom, like a rock. "This object is sinking," all agree.

"Okay," continues Mr. Hutcheon, "we are ready to explore materials," and the students form their science groups. Mr. Hutcheon's class uses the same types of groups as Ms. Parker's class in Chapter 2. Each group has jobs labeled *director, recorder, materials manager*, and *speaker*. This is an extension of a model developed by the educators at Biological Sciences Curriculum Study and revised by the Australian Academy of Sciences (1996).

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The only directions that Mr. Hutcheon gives the students before they secure their materials are to fill their basins with water, make predictions about each of the objects, and then test whether they sink or float. Students need to keep a record of their science work in a personal science notebook. Mr. Hutcheon does not give out a worksheet, but for this unit the students are instructed to place the question "Why do objects sink or float" in their science notebooks.

My thinking: I am impressed that students are keeping their own science notes and not relying solely on worksheets. Often, in seventh grade, students see completing the worksheet as the goal of the exploration. This is clearly not the case here. Mr. Hutcheon is interested in fostering understanding.

Watching the students work is a treat; they are interested in all the objects and can relate to them. The recorder for each group goes up to the board to enter the group's data in a chart. The following list represents the consensus of the class.

Object	Sink or Float?
Corks	Float
Candle	Float
Marble	Sink
Chalk	Sink
Block of wood	Float
Coin	Sink
Apple	Float
Potato	Sink
Plasticine	Float and sink

"Let's look at our data," says Mr. Hutcheon. "Did anything surprise you?" he asks. Hands fly up. One student remarks that "I thought the chalk would float because it is so light, and I thought the candle would sink." "I didn't think we could get the Plasticine to float, because at first it sank straight down," says another student. "But then we spread it into a different shape, kind of like a boat, and it floated." "Yeah, and why do apples float but potatoes sink?" asks yet another. Mr. Hutcheon asks them to think about the following questions, which he lists on the board:

- Do all light things float?
- Why can a block of wood float, while a small piece of chalk sinks?
- Can a log of the same type of wood float?
- Will a shorter candle float or sink?
- Why did the Plasticine float when it was reshaped?

Students grapple with these questions. Mr. Hutcheon invites the class to consider one student's comment: "Katie says that the potato has greater density than the apple. Let's take this theory as a starting point and see if we can test it. What do you mean by density, Katie?" Katie is not sure exactly how to define the term, but says it has something to do with the particles the object is made of. Mr. Hutcheon records this observation on the board. Luke then suggests that the apple core has air spaces where the seeds are located, and the potato does not. Mr. Hutcheon writes this idea, too, on the board. Kara suggests that the skin of the apple is waxy and acts like a waterproof shield. Jenna suggests that maybe a small piece of potato would float.

My thinking: I presume that these students have had science experiences like the ones in Ms. Drescher's and Ms. Sacco's classes because they are quick to offer ideas. Clearly, the concept of density

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is not unfamiliar to them, but they have much to learn about it. I'm eager to see how Mr. Hutcheon can build on their prior knowledge.

Mr. Hutcheon asks the students to design investigations to test their ideas. He cautions them to be careful with the plastic knives, and he walks around the room assisting. I walk around the room, too. Students in one group decide to peel the apple and the potato. Another group of students is coring the apple. All the students are busy exploring their own questions.

One group of students is intent on finding a piece of apple that sinks. But the students discover that with or without the core and with or without the skin, apple slices float! Other students peel and slice the potato but cannot get the potato slices to float, no matter how small they make the pieces.

Mr. Hutcheon's thinking: *By having the students explore the many different ways to try the apple and potato in water, he is hoping to get them to understand a qualitative way of describing density.*

Before time runs out, Mr. Hutcheon asks the materials managers to return the materials, and the class cleans up the mess left from the potato, apple peels, and water. Mr. Hutcheon then pulls the class together by asking the students why they think the apple floated and the potato did not. Finally, Megan says, "The fibers in the potato are packed together more tightly than the fibers in the apple." Mr. Hutcheon asks the class to reflect on Megan's reasoning, and there is consensus that it is correct. Katie remarks that Megan's explanation means that the potato has greater density than the apple. Mr. Hutcheon writes this definition for density on the board: "How closely packed together the particles are."

My thinking: *I notice how much this definition of density resembles the one that Ms. Drescher offered her fifth-grade students. These seventh-grade students, however, have developed the definition for themselves. They are taking their reasoning to a new level.*

The Following Days: Further Tests and Measurements

For the following class, Mr. Hutcheon prepares circular cookie cutters along with peeled pieces of apple and potato. He asks the students, working in the same groups as the prior day, to use the cutters to make a piece of potato that is exactly the same size as a piece of apple. They should then compare the two pieces in any way they can. The students place the cut slices in their basins and then ask if they can weigh them. "Of course," Mr. Hutcheon replies, and the students use the scale to learn that the potato weighs more for its size than the apple.

For the next class, Mr. Hutcheon does a demonstration in a very large, clear plastic basin using four pieces of wood cut to exactly the same size. In mathematical terms, these wooden blocks are rectangular solids, and Mr. Hutcheon asks for student volunteers to help him measure their length, width, and height. Each block measures 7 cm long, 4 cm wide, and 2 cm high. Using these measurements, the students compute the volume by multiplying length by width by height. Luke gives the answer as 56 cubic centimeters. The class agrees that each block of wood has this same volume.

My thinking: *This is a more teacher-directed lesson than the earlier one, but it seems appropriate at this stage now that the students have done their own experiments with sinking and floating. This is an example of the teacher providing information when it is necessary, and the timing is right.*

Now the students examine other characteristics of the four blocks of wood. Collecting their observations, they note that one block has very little visible wood grain, whereas two other samples have more wood graining. The fourth sample is a black piece of wood, and one student asks if it is painted black. Mr. Hutcheon asks him to examine it to determine that it does not have paint on it. Each wood sample has a number, and this black block is number 4.

Now Mr. Hutcheon asks the class how these four blocks will behave in water. All the students believe that all four blocks will float. After all, the wood floated in their earlier experiment. Mr. Hutcheon gently lowers each sample into the water. Number 1 appears to stay on the surface; number 2 floats but part of it is submerged; and number 3 floats with even more submerged. When number 4 goes into the basin, it sinks!

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TABLE 7.2 Data for the Blocks of Wood in the Density Investigation by Mr. Hutcheon's Class

Wood Sample	Mass	Volume
1	6 g	56 cm^3
2	30 g	56 cm^3
3	43 g	56 cm^3
4	62 g	56 cm^3

Using a digital scale, students now determine the mass of each of the four blocks of wood. Mr. Hutcheon lists the data in a chart on the board (Table 7.2). He invites the students to study the table and draw some conclusions about the patterns they may see emerging. Rather quickly, they notice that the lower in the water the wood block floated, the more it weighed and that the black wood sample weighed the most for its size. Mr. Hutcheon then asks the students to divide the mass of each block of wood by its volume and compare the resulting numbers.

One student wants to know the identities of the four types of wood, and Mr. Hutcheon supplies the names: number 1 is balsa, number 2 is pine, number 3 is oak, and number 4 is ebony. "Is that the same type of ebony used for piano keys?" Katrina asks, and Mr. Hutcheon says, "Yes."

After dividing the mass by the volume for each sample, the students see that only ebony, at 1.10, has a number greater than 1. Mr. Hutcheon decides to help the students analyze that number by offering the idea that for every 1 cubic centimeter of ebony, there is a mass of 1.10 grams. He asks the students to think about this as another way of describing density—the amount of mass per unit volume of an object. Balsa's density is only 0.10 gram per cubic centimeter, pine's is 0.54 gram per cubic centimeter, and oak's is 0.76 gram per cubic centimeter.

"What about the density of water?" Mr. Hutcheon wonders. Katie remembers that water's density is 1 gram per cubic centimeter. So Mr. Hutcheon asks for a conclusion based on the class's observations and data. Luke offers that objects that have a density less than 1 will float on water, and those with a density greater than 1 will not float. Mr. Hutcheon remarks that they are off to a good start in understanding why some things float and some things do not float.

My thinking: *How wonderful that Mr. Hutcheon calls this conclusion a "start"! The students have reached the "right" answer, but he knows that floating and sinking involve many complex variables, including the concept of buoyancy and the ways in which you can change the density of water.*

When the materials are cleaned up and scales are put away, Mr. Hutcheon uses the SMART Board (an interactive whiteboard) in his room and accesses a website on buoyancy from his laptop. There the students observe animated illustrations and an explanation of blocks of pine and oak submerging to different levels in the water. The students are excited by this visualization since it resembles what they have just experienced. "That's cool," one student remarks; another says, "We just did that." The website helps students visualize the water displaced by the blocks and connect the weight of the displaced water with the weight of the wood and the upward force of buoyancy.

My thinking: *I am impressed by Mr. Hutcheon's use of the Internet to provide another approach to sinking and floating and to connect the concept of buoyancy to the concept of density. The visualization helps students with diverse learning styles see this concept in yet another way.*

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For homework, Mr. Hutcheon asks the class to consider why the ball of Plasticine did not float but a boatlike shape made from the *same* ball did float. He asks them to ponder why ships made of heavy metal can float.

The Teaching Ideas behind This Story

- Understanding takes time. The time that these seventh-grade students took to explore the many ways apples and potatoes can float or sink prepared them to consider a deeply complex concept—comparing an object's volume and weight. This is an essential concept that underlies density as well as sinking and floating, and it is appropriate for teachers to visit and revisit this concept in elementary and middle school science.
- The students ultimately arrived at the mathematical definition of density: mass per unit volume. But first they defined density in a qualitative way, and this gave them a context for the mathematics. Often well-meaning teachers give numbers without providing prior meaning.
- In Mr. Hutcheon's class, one further activity was to look at longer and shorter pieces of candle to see if a longer piece would float lower in the water. Another activity involved displacing water again (Figure 7.2) to determine the volume of an irregularly shaped object. Students explored the Plasticine ball again and came to realize that altering its shape changed its volume. Keeping this topic complex led to many activities and opportunities for meaning making that would carry the students on to higher grades.

The Science Ideas behind This Story

- An object *floats* in water when it is supported by a buoyant force, even if no part of the object is above the surface of the water.
- Objects that float in water displace water. For a floating object, the mass of the water displaced is equal to the mass of the object.
- Objects that sink in water also displace water. For an object that sinks, the *volume* of water displaced is equal to the volume of the object, as shown in Figure 7.2.
- Ships float because of their size, shape, the density of the materials they are made of, the amount of air inside them—and, fundamentally, because of buoyancy. Ships displace a mass of water equal to the

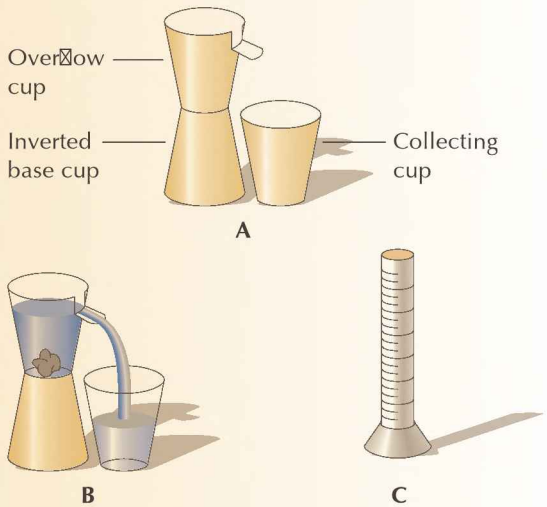

FIGURE 7.2 An experiment in measuring water displacement
(A) Three plastic cups are arranged so that the one with a cut-out spout overflows into a collecting cup. To begin the experiment, the overflow cup is full and the collecting cup empty. (B) A small stone weighing 100 grams, with a volume of 40 cubic centimeters, is placed gently in the overflow cup. The stone sinks, causing water to overflow into the collecting cup. (C) The water from the collecting cup is measured in a graduated cylinder, indicating that 40 milliliters (cubic centimeters) of water were displaced. Thus, the volume of displaced water equals the volume of the stone.

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Measuring Water Displacement

Would you like to see how much water is displaced when a small object sinks or floats in water? Using three soft plastic cups and a graduated cylinder, you can perform your own test.

Take a plastic cup and cut a slit in it about 5 centimeters long and 2.5 centimeters wide. Fold this flap down like a spout. Then stand this cup on another cup that has been inverted, so its bottom is facing up. Place a smaller cup beneath the spout you have cut (see Figure 7.2).

Next, fill your cup with the flap until it overflows. Check that the overflow water is falling into the small cup; then discard this first bit of overflow water.

Your cup with the flap should now be perfectly full, up to the level of the spout. Gently place a small object in this cup. Take the displaced water that collects in your small cup and measure it with a graduated cylinder. Are you surprised by the amount?

ship's mass, and this creates a large buoyant force equal to the mass of the water displaced. Ship designers know how to shape a ship to maximize this buoyancy effect.

- When the ball of Plasticine is shaped into a boat, the material now contains air and has less overall density than it had as a ball. Shape counts!

Connections to the Next Generation Science Standards

- **NGSS DCIs: MS-PS1-2 and MS-PS1-3: Structure and Properties of Matter:** Each pure substance has characteristic physical and chemical properties (in bulk quantity) that can be used to identify it.
- **NGSS SEPs:** Students are *asking questions and defining problems; planning and carrying out investigations; analyzing and interpreting data; using mathematical and computational thinking; engaging in argument from evidence;* and *observing, evaluating, and communicating information.*
- **NGSS CCs:** Students observe *structure and function* and interact with phenomena with attention to *scale, proportion, and quantity.*

In his use of the animated website on buoyancy, Mr. Hutcheon also illustrated part of the National Technology Standards for Teachers (NETS-T). The standard on "digital-age learning experiences" specifies that teachers should use contemporary technology to "customize and personalize learning activities to address students' diverse learning styles" (International Society for Technology in Education, 2008).

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- Will an object float at different levels in different liquids?
- Can you make a floater into a sinker?
- Can you make a sinker into a floater?
- Why do rotten eggs float and raw eggs sink? How about hardboiled eggs?

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7-7a Deepening of Understandings

In our final density story, we visited the same basic core science concepts in yet another grade. You should be able to see how this learning progression gradually deepens the students' knowledge and leads them to ever more sophisticated levels of understanding. We begin with an understanding of the properties of matter and move to the importance of measuring physical magnitudes like weight and volume. We extend the young students' knowledge of materials by presenting them with a wide range of different materials that have specific properties, some of them fixed and some of them variable. By considering why specific materials behave the way they do, the students in this chapter make connections to the composition of the materials—the fruits, vegetables, liquids, and blocks of wood. In the course of these investigations, the students are learning to represent and record data in useful ways and they are deepening their understanding of the nature of matter.

As learners grow, they do not simply stuff new science concepts into their heads. Instead, certain concepts get subsumed or altered by new, more complex ones. Since we know from the research on alternative conceptions that learners do not easily part with ideas, this frequent revisiting of embedded concepts is essential to help students reach a deep and meaningful level of understanding.

In the next two chapters, we explore additional activities for the upper elementary grades and middle school years. As you read, think about the prior experiences that help students construct new ideas in these grades. Also consider how the middle years themselves offer prior knowledge that students will need to engage in more intense science study in high school and beyond.

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CHAPTER 8

Using Models and Engineering Design for Teaching and Learning Science

Next Generation Science Standards

- **Crosscutting Concepts:** 1, 2, 3, 4, 6, 7
- **Disciplinary Core Ideas:** 3–5-ETS1-1, 3–5-ETS1-2, 5-ESS1-2, MS-ESS1-1, MS-ESS1-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4, MS-PS1-1, MS-PS1-2, MS-PS1-3
- **Science and Engineering Practices:** 1, 2, 3, 4, 5, 6, 7, 8

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 8-1 Understand how modeling helps to explain natural phenomena.
- 8-2 Explore how a physical model of the solar system provides context for the science ideas to be learned.
- 8-3 Examine how modeling leads to meaning making.
- 8-4 Discuss how moon phase journaling can lead to models of natural phenomena.
- 8-5 Understand the connection between developing models and engineering design.
- 8-6 Analyze how a design challenge incorporates engineering practices.

Reflection To Think About:

- What models have you made? Did you ever build a model airplane? A clay model? An abstract model? A computer model?
- What objects of nature require a model for direct exploration?
- How can making models facilitate learning?
- Where can you find virtual models of natural phenomena?

I have just returned from visiting the planets Mars, Jupiter, and Saturn. It was an exciting trip that revealed so many details of these planets—my, how huge Jupiter is! It took much longer to reach Jupiter from Earth than to reach Mars.

Okay, this was a virtual trip, but the views were breathtaking, and knowing I could "travel" anywhere in our solar system or the entire universe with my computer mouse was quite exciting. I was using the WorldWide Telescope available on the Internet. Replete with real images from the finest space and ground telescopes, this computer portal allows the viewer to visit real images in the solar system, the Milky Way galaxy, and beyond to other galaxies. I started on planet Earth, traveled to Mars, then Jupiter, and then on to Saturn and back to Earth. It was a quick trip in real time, but I began to get a feeling for celestial relationships: the planets that are closer to us and those that are further; those that are much bigger than ours and those that are smaller.

This computer visualization of the universe is just one type of model. This chapter explores the use of various kinds of models in science education. The activities you have been reading about in earlier chapters invite students to become directly involved with their objects of study. Sometimes, however, it is not possible to explore the objects directly. They are too large or too small, too hot or too cold, too far away, or inaccessible for other reasons. In these cases, students and teachers can use models, physical or virtual, to learn a great deal about the natural world. Additionally, developing models of phenomena that we can study directly gives us added insight into the science concepts.

8-1 The Usefulness of Models

model
A representation of a system or object: for example, a physical structure that imitates a smaller or larger structure, a mental construct that represents an object or process, or a computer program that parallels the workings of a larger system.

When scientists are unable to work directly with materials, they construct models of them in an effort to gain a better understanding of their structure and function. A **model** may be a physical structure, either a smaller or a larger representation of a system or an object. For example, when I was in fifth grade, I made a model of a tooth for Dental Health Week in my elementary school. In order to build it, I needed to gather pictures of teeth and understand the various parts of a tooth. I had to decide which type of tooth to represent as well as figure out the size and composition of the model. What I remember most from making that tooth model—aside from my struggle to create the plaster mold out of clay—was that, to my surprise, the tooth is a complicated structure with lots of layers. In daily life we see only the crown, the visible part of a tooth.

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My model, though, included markings to show where the root canal, the nerve, and the pulp are.

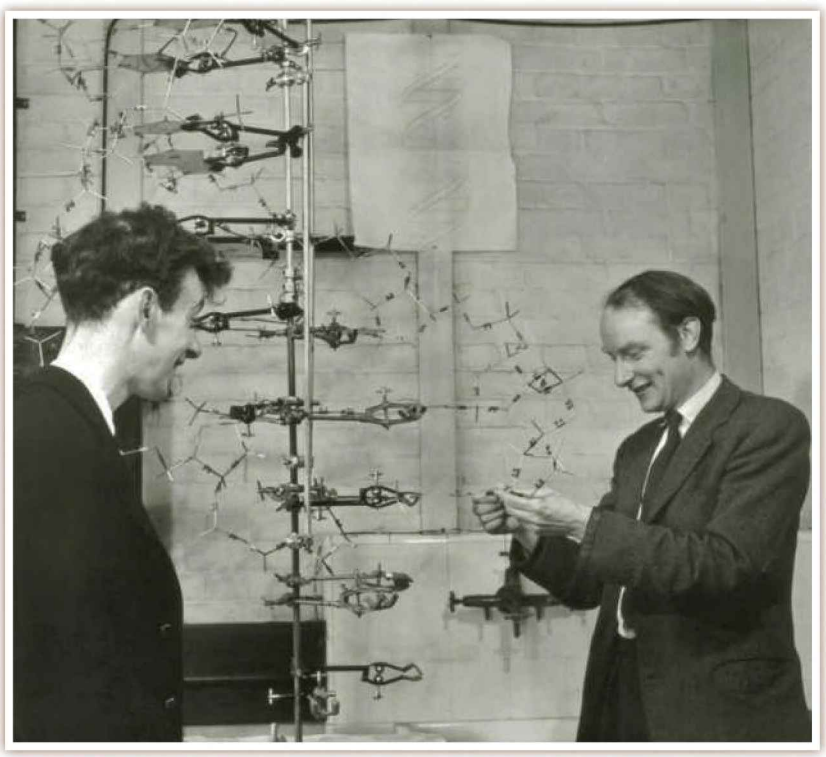
Although not exact by any means, my model tooth remained on display for all of Dental Health Week. Moreover, I never *forgot* the structure of a tooth. Decades later, when I needed to have the contents of the pulp chamber of one of my molars removed because it was infected, I pictured the root canal from my model.

Similarly, scientists have long made physical models out of whatever materials are available to them. One of the most famous models involved the chemical structure of deoxyribonucleic acid, known as DNA—the material in our cells that passes genetic information from one generation to the next. The model—developed by scientists James Watson, Francis Crick, Rosalind Franklin, and Maurice Wilkins—marked one of the most important scientific revolutions of the twentieth century and was made out of materials resembling giant tinker toys.

Scientists construct models after they have gathered enough data about their objects of study to begin to make a reasonable facsimile. In the case of DNA, the scientists used data from an x-ray crystallography method employed at the time by Rosalind Franklin. Dr. Franklin was able to gather images of patterns made by the DNA molecule when it reflected x-rays. Her data became the basis for Watson and Crick's DNA model (Photo 8.1). Unfortunately, she died before her three team members were awarded the Nobel Prize for science and medicine for their remarkable discovery.

8-1a What Do We Mean by a Model?

A model does not have to be something you can touch. It may be a mental construct—a design that forms an image in your mind representing a concrete process or object. For example, I carry a mental model of an atom in my mind; it is the way I have conceptualized an atom on the basis of what I have learned.



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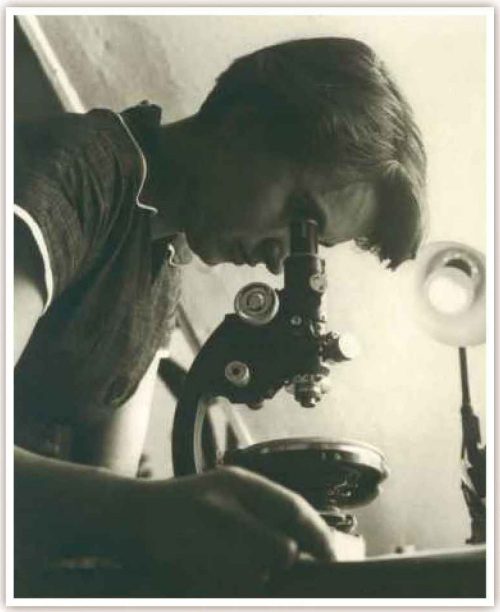

Science Source/Getty Images

PHOTO 8.1 James Watson, Frances Crick, and Rosalind Franklin built a double helical model of DNA.

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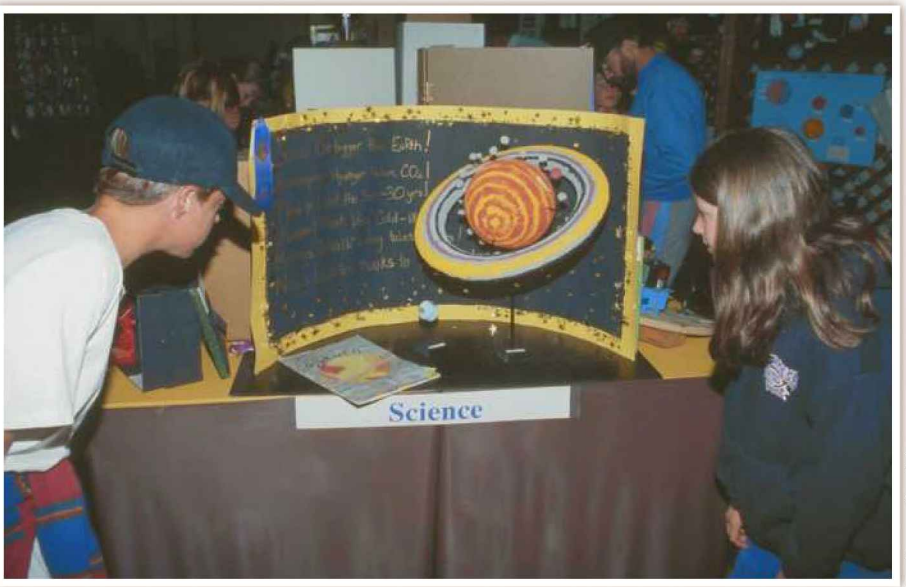

Tony Freeman/PhotoEdit

PHOTO 8.2 We construct models in order to make meaning of objects that are impossible to study through direct manipulation. Students created this model of Saturn to help conceptualize their information about the planet.

Models can also be virtual, computer-generated images, or large-scale virtual constructions. The WorldWide Telescope is described as a "visualization software environment" (WorldWide Telescope, 2015). Today, a great deal of scientific research is performed by using computer models of varying degrees of complexity. As just one example, meteorologists often explore potential weather events by using computer simulations based on actual weather satellite data. You see the results of these computer models on the television news each day when forecasters describe the possible tracks a storm system may take.

8-2 An Edible Solar System

As you will discover from the following science stories, making models is a way of furthering your students' understandings of objects and events that they cannot manipulate directly (Photo 8.2). Model making can take place at any level of science education. First, we will see what happens when Mr. Johnston and his fifth-grade class build and explore a model of the solar system and students make drawings of orbits. Then we will see eighth graders construct models of atoms employing principles of engineering design.

SCIENCE STORY

An Edible Solar System

Mr. Johnston is a veteran elementary school teacher. He has a science room in a small, suburban elementary school, and students visit his room once a week with their classroom teacher. Together the students engage in science activities in Mr. Johnston's science room, which they then continue in their

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regular classroom. There are interesting materials on display and arranged in storage cabinets all around the room. Three hamsters, a rabbit, and numerous plants share the room with Mr. Johnston.

This particular day, when fifth graders arrive for their morning visit, the only materials Mr. Johnston has set out are round fruits and vegetables of varying sizes: grapes, peas, cabbages, grapefruits, melons of different types, apples of varying sizes, oranges, apricots, and small tomatoes.

"Are we dissecting fruits and vegetables again?" the students ask.

Mr. Johnston laughs. "No," he says. "We are going to use these fruits and vegetables to make a model of the planets in our solar system."

The students have been exploring "objects in the sky," and they have just completed a huge poster-board model of the sun, so this project makes sense to them. They are excited to begin. "How do we do it?" they ask.

Mr. Johnston explains that they need to gather a lot of information before they can use these materials to make a model. "Remember all the research we did on the sun?" he asks. "What type of information do we need about the solar system in order to construct a reasonable classroom model?"

The students brainstorm various questions to answer, including the following:

- What are all the objects in the solar system?
- How far away from Earth are the rest of the planets?
- How many moons does each planet have?
- What are the planets made of?
- How many planets have atmospheres?
- How big are the planets?
- How far away from the sun is each planet?
- What colors are the planets?
- Is Pluto a planet?

Mr. Johnston records these questions on poster paper as the students record them in their science notebooks. He invites the students to work in groups of four and to decide on the particular questions they want to research. He explains that they are in the "data-gathering" phase of this model-making project, and they must select the questions they are most interested in exploring.

At this point, Mr. Johnston also shares the story of Pluto with the class because it is an opportunity to talk about how scientists classify objects in the sky. He explains that Pluto was discovered in 1930 by the astronomer Clyde Tombaugh and was originally classified as a planet. Since that time, we have developed stronger telescopes, including the Hubble Space Telescope, and we have learned more about the outer reaches of the solar system. In 2006, as a result of our recent learning, Pluto was reclassified as a "dwarf planet" rather than a regular planet—leaving only eight planets in our solar system. Mr. Johnston invites the students to find out why. As a hint, he asks them to learn what attributes define a planet.

> ***My thinking:*** *I am impressed with the way Mr. Johnston offers important information about Pluto but does not give the class the entire story—just enough to get them interested! It is a challenge to know how much to give and how much to require of the students as the groups construct their understanding of the solar system.*

Mr. Johnston has had the WorldWide Telescope software downloaded on the science classroom laptops, and he used the website on his SMART Board to introduce the "Objects in the Sky" unit. He encourages the students to use the laptops to go on the WorldWide Telescope. Mr. Johnston assures the students that they can use this exciting resource, and he points out that they also can access other planetary websites for accurate data about the planets. Their goal, he reminds them, is to find data they need to construct a model with their fruits and vegetables. He explains how researching the problem of how to use the fruits and vegetables to make a model of the solar system requires time and patience. The students need to gather a lot of data about each planet before they select the fruits of relative sizes for their solar system model.

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> *Given a three meter sun at one end of the [school] building, the scale model planets we created wouldn't fit in the school. In fact, Pluto would be nearly 15 km away.*
> —DAVID WHITNEY

The students access the Internet and accumulate a good deal of information about the planets individually and the solar system as a whole. All the students decide that one critical piece of information is the planets' distances from the sun. Here Mr. Johnston intervenes again, explaining that the distances between the planets and from the planets to the sun are so huge that no classroom model can be truly accurate for distance. He tells the students that one fourth-grade teacher, in an effort to represent the distances accurately, spread out the model planets all over the local community (Whitney, 1995).

Mr. Johnston's thinking: *Mr. Johnston knows that the fruit-and-vegetable model will not be completely accurate, but that is okay, especially if the students come to understand how it resembles the real solar system and how it differs. Later, he will ask them to make comparisons between the model and the real thing.*

To make the calculations more manageable, Mr. Johnston provides the students with distance dimensions in the form of astronomical units. One astronomical unit (AU) equals 93 million miles, the average distance from the sun to the Earth. All the other distances in AUs are relative to that distance. Mr. Johnston distributes calculators to help the students explore the numbers while he uses the SMART Board at the front of the room to write the data (shown in Table 8.1). Together, the students multiply each of the planetary distances expressed in AUs by 93 million miles. The enormity of the numbers indicates to the class how huge the solar system really is.

Now the students turn to the data they have collected on planet diameters, which is given in kilometers (see Table 8.1). Using these data, the students order the planets from smallest to largest. Then they are ready to select the fruits and vegetables that are most representative of the solar system.

For the sun, they choose a huge pumpkin brought in by Mr. Johnston. In reality, the sun's diameter is about 109 times that of Earth, and if the sun were a hollow ball, one million Earths would fit inside. Thus

TABLE 8.1 The Solar System Data Used by Mr. Johnston's Class

Planet	Average Distance from Sun (AUs)	Diameter (km)
Mercury	0.4	4,878
Venus	0.7	12,104
Earth	1.0	12,756
Mars	1.5	6,796
Jupiter	5.2	142,796
Saturn	8.5	120,300
Uranus	18.0	52,400
Neptune	30.0	48,600

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the students know that the pumpkin is not really big enough to accurately represent the sun in their model. As for the planets, different groups of students make different decisions. Here are the choices one group makes:

- Mercury: a small cherry tomato
- Venus: an orange
- Earth: an apple, slightly larger than the orange
- Mars: an apricot, approximately half the size of the apple
- Jupiter: a honeydew melon
- Saturn: a cantaloupe
- Uranus: a cabbage
- Neptune: a grapefruit, slightly smaller than the cabbage

For many students, it becomes a challenge to remember which fruit is modeling which planet, so Mr. Johnston instructs each group to make a key.

Once the students have made their selections, it is time to go outside and place the model planets in such a way that they also model the relative distances of the planets from each other and the sun. The class chooses the set of vegetables and fruits just listed as the ones to take outside. Mr. Johnston suggests using 1 meter to represent 1 AU. With this technique, the students observe that the first four planets occupy about 1.5 meters of space, while Neptune is 30 meters away from the pumpkin, the designated sun. The student carrying the grapefruit model of Neptune finds it difficult to see the student carrying the huge pumpkin model of the sun (Figure 8.1).

When the students discuss their model back inside in the classroom, Mr. Johnston asks, "In what ways is our model like the real solar system?" The students offer many responses, including these:

- "All the planets are different, with different textures and insides."
- "The relative sizes of the planets are the same, more or less."
- "We set them up so the relative distances are similar."
- "They're in the order of their distance from the sun."

"In what ways is the model *different* from the real solar system?" Mr. Johnston then asks.

"You can't eat the real planets!" the students point out. And they add other differences as well:

- "The model is so much smaller than the real thing."
- "The planets aren't moving."

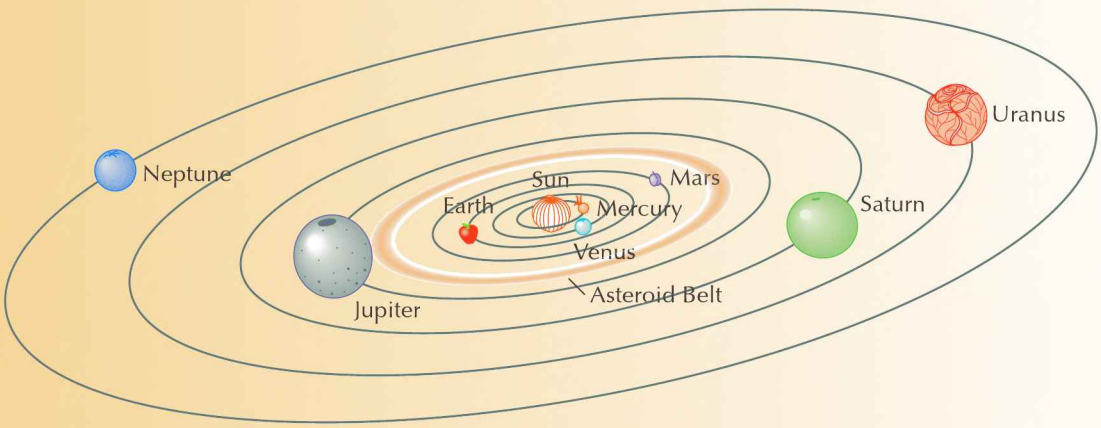

FIGURE 8.1 A model of the solar system using the edible "planets" chosen by Mr. Johnston's class

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- "The distances are much, much larger."
- "Some planets have moons."
- "Neptune is blue, not yellow like the grapefruit!"

Mr. Johnston's thinking: *The students are doing a good job of evaluating this particular model, and they are beginning to learn a crucial fact about models in general: You should always be aware of how your model differs from the reality it represents. The students are seeking the best solution.*

The remark about planets having moons leads to an interest in adding moons to the model. On another day, the class decides to use miniature marshmallows and toothpicks to represent the moons of the various planets. From their research, the students learn that Mercury and Venus have no moons, but there are more than 155 moons that orbit the rest of the planets in the solar system. Jupiter, with more than 60 moons, has the most. In fact, scientists are still discovering new moons in the solar system. This activity generates further questions. For example, one group wonders if the mini-marshmallow moons are on a similar scale to the planets. They do some research on the Earth's moon and the moons of Jupiter, and they realize that a regular-size marshmallow would be a better model for our moon, which is about one-fifth the size of the apple Earth. They also realize that it would be difficult to include all the planets' moons in their model.

To conclude the lesson, Mr. Johnston asks the students to observe their models closely, think about what they have learned, and write their conclusions in their science notebooks. He asks them to be sure to answer these questions:

- What planets seem similar in size to one another?
- What planets are Earth's neighbors in the solar system?
- What place in the solar system is the Earth in order of distance from the sun? In order of size?
- What is the solar system mostly made up of?

The students finish the session by eating their favorite parts of the model.

The Teaching Ideas behind This Story

- Inviting the students to generate their own questions about the solar system is a first step toward giving them ownership of the process of gathering the data.
- Typically, solar-system models are constructed out of Styrofoam balls of varying sizes. The assumption people may make when observing this type of model is that all the planets are the same except for their size. That is not true. Planets differ from each other not only in size but also in composition, color, and surface features. For that reason, Mr. Johnston thinks that fruits and vegetables will make a better representation as well as a more interesting one.
- Notice how Mr. Johnston encourages students to discover both the accuracies of their model and its limitations. He also encourages them to learn about Pluto's demotion from a planet to a dwarf planet.
- This experience of gathering data and creating an edible solar system model is directed toward students in fourth grade and higher. You can adapt the activity for students in earlier grades. Instead of numerical data, you can use precut circles to represent the relative sizes of the planets. Students can select their fruits and vegetables using these circles as their data. In the younger grades, each astronomical unit becomes one "giant step."
- It is the teacher's job to select a variety of fruits and vegetables that work as models. Using your data, choose carefully. Obviously fruits are not of uniform size, so your selections will be based on the season and the fruits that are available where you live.
- Notice how Mr. Johnston weaves technology into the lesson without letting it become an end in itself. The use of the WorldWide Telescope helps students visualize the planets and comprehend the

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NASA Marshall Space Flight Center (NASA-MSFC)

PHOTO 8.3 An image of Saturn from the WorldWide Telescope. How does this compare with the model shown in Photo 8.2?

vast distances between the planets and the sun. (See Photo 8.3.) But Mr. Johnston also wants the students to gather numerical data and build a more traditional, hands-on model that will lead to detailed comparisons and contrasts. There is a significant difference between using a computer model to explore remote objects and building your own model with the data you collect.

- You can think of model building as a step toward model manipulation, which itself leads to further research, more model building, and deeper understanding. The success of the model is measured by comparing it to their data about each planet.

The Science Ideas behind This Story

- Our **solar system** is made up of a group of heavenly bodies that move around the sun. The main members of the solar system are the eight **planets.** If you cannot take your students outside as Mr. Johnston did, you can use Table 8.2 to construct a model of planetary distances inside the classroom.
- **Stars** shine by producing their own light.
- The sun is the only member of the solar system that is a star.
- Planets shine by reflecting the light of the sun or of other stars.
- All planets travel in their own **orbits** (closed paths) around the sun, moving counterclockwise around the sun from west to east.
- The Earth is the third planet from the sun in a system that includes the moon, the sun, seven other planets and their moons, and smaller objects, such as asteroids and comets. The sun, an average star, is the central and largest body in the solar system.
- Between Mars and Jupiter is a belt of several thousand **asteroids** of different sizes. These are like tiny chunks of planet, and they also move around the sun.

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TABLE 8.2 Relative Planetary Distances Expressed in Units Suitable for a Classroom Model

Planet	Distance from the Point Representing the Sun
Mercury	1.75 inches
Venus	3.25 inches
Earth	4.75 inches
Mars	7.0 inches
Jupiter	2 feet
Saturn	3 feet, 8 inches
Uranus	7 feet, 5 inches
Neptune	11 feet, 8 inches

- Pluto belongs to another belt of large asteroids called the Kuiper belt. Though these asteroids revolve around the sun as a group, Pluto is not even the largest object in this belt. The definition of a planet requires that it be the dominant gravitational body in its orbit in the solar system. Therefore, in 2006, when an object slightly larger than Pluto was found in the Kuiper belt, astronomers voted to reclassify Pluto as a dwarf planet.
- Scientists continue to seek a larger body than Pluto that can meet the criteria for a new ninth planet!

Connections to the Next Generation Science Standards

- **NGSS DCIs:**
  - **3–5-ETS1-1: Defining and Delimiting Engineering Problems:** Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria).
  - **3–5-ETS1-2: Developing Possible Solutions:** Research on a problem should be carried out before beginning to design a solution. At whatever stage, communicating with peers about the proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.
  - **5-ESS1-2: Earth and the Solar System:** The orbits of Earth around the sun and of the moon around the Earth, together with the rotation of the Earth on its axis, cause observable patterns. These include day and night; daily changes in the length and direction of shadows; and different positions of the sun, moon, and stars at different times of the day, month, and year.
- **NGSS SEPs:** Students engaged in *developing and using models*; *analyzing and interpreting data*; *arguing from evidence*; and *using mathematical and computational thinking*.
- **NGSS CCs:** Students were engaging with identifying *patterns*, *cause and effect*, and *scale, proportion, and quantity* and systems and system models.

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Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- What other round objects with diverse colors and textures could model the solar system?
- Suppose you could not find a large pumpkin. What else could you use to model the sun? Why is any object representing the sun in this model—really an inaccuracy?
- What can you learn by planet-hopping with the WorldWide Telescope?
- How does the sun make its own light?
- What are the three basic attributes of a planet?

8-3 From Models to Meaning

solar system
The sun and the group of heavenly bodies that move around it. The sun is the only member of our solar system that is a star.

planets
Principal members of the solar system that move around the sun. In order of their distance from the sun, the planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Planets shine by reflecting the light of the sun or other stars.

star
A heavenly body that produces its own light. There are billions of stars in the universe, including our sun. About 3,000 stars are visible with the naked eye.

orbit
The path of one heavenly body as it travels around another heavenly body.

I have often built an edible solar system with elementary school students, and they tend to remember the project for years afterward. The first time was in my daughter's third-grade class. At her high school graduation, a former third-grade classmate of hers greeted me and said, "I remember when you visited our class and the huge honeydew melon was Jupiter."

The fruits and vegetables make a very useful model for all students, especially for those who need to work with concrete objects to shape comparisons and interpret data. In the same way, using the WorldWide Telescope was a valuable way for students to gather data in order to build their model. But remember that these models were not ends in themselves. Both were steps toward developing a meaningful understanding of the objects in the solar system. In Mr. Johnston's class, the initial activities generated further research, as when one group wondered about the sizes of moons and decided to research the topic.

Making a model and interpreting data based on the model, exploring comparisons between the model and the real object, moving the model as though it were the real thing—these types of activities have important implications for future learning. Besides facilitating the understanding of abstract concepts, the use of models helps to prepare students for the science concepts they will encounter in later grades. For example, balancing chemical equations involves using chemical symbols and a mathematical process to model the actions of real atoms and molecules. As we will see later in this chapter, mental and concrete models of atoms help when thinking about chemical reactions.

In this next science story, Mr. Johnston's fifth graders explore the properties of the planets' orbital paths around the sun. This lesson requires another type of model making.

SCIENCE STORY

Making a Model of a Planetary Orbit

On another day, Mr. Johnston distributes string, pencils, centimeter rulers, and pushpins to the class. He asks the students to work with a partner and explains that they are going to draw a shape that represents the path of planets around the sun.

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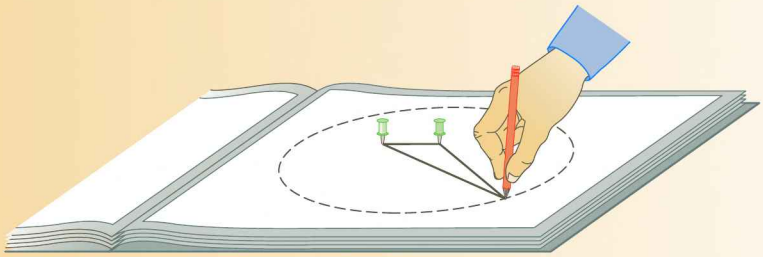

FIGURE 8.2 Drawing an ellipse (oval) with a pencil, string, and two pushpins

First, he has each pair of students tie a loop with a string about 30 centimeters long. Then he invites them to insert two pushpins toward the middle of one of their science notebook pages, placing them about 8 centimeters apart and making sure the pins go through several pages. The pins should be anchored securely, Mr. Johnston explains. He goes around the room and supervises as each pair of students sets up the pushpins.

Now the students are ready to proceed. They place the loop of string over the pushpins. Then, anchoring a pencil in the loop and keeping the loop taut, they trace a figure that resembles an oval (Figure 8.2). Each team of students compares its shape with those drawn by others. Indeed, the shape is always oval, no matter who draws it.

Mr. Johnston tells them that another word for this oval shape is **ellipse**, and he asks them to label the two points where they inserted their pushpins the **foci** of the ellipse. "In what way is this image different from a circle?" he then asks.

The students say that "you can draw a circle with just one pushpin." Also, they remark, a circle has a center, but the oval does not have one center. Mr. Johnston explains that the planets travel in an elliptical orbit around the sun. We can think of the sun, he says, as being located at one of the foci of the ellipse.

Mr. Johnston has also hung three large, thick pieces of white foam board from hooks at the top of the chalkboard. Each piece is about 1 meter square. He invites students to come up and place pushpins at different points on the foam board. Then he suggests that the students use string loops of varying lengths to determine in what ways the shape of the ellipse changes when the length of the string and the distance between the foci change. (For safety, Mr. Johnston distributes the pins only when the students come up to the board.)

"Be sure to measure the distance between the pins and the length of the string you use in centimeters," he reminds the students. "Record your data in your science notebooks." He watches as the students draw their different ellipses on the foam boards.

Mr. Johnston's thinking: *Mr. Johnston knows that the students' new pencil tracings will change in shape as the length of the string and the distances between the pins increase. The challenge for the students will be to make the leap from these pencil images to the changes in the orbital path of a planet when its distance from the sun increases.*

The students do notice how exaggerated the elliptical shape becomes as they increase the distance between the pins. Mr. Johnston suggests that they keep the distance between the two pushpins constant, changing only the length of the string, and they try the experiment in that way.

"Now, let's imagine that any one of these ellipses represents the orbital path of the Earth around the sun," Mr. Johnston suggests. He labels one of the foci with an *S*, for the sun. "Let's draw a line that represents the distance from the sun to the point on the ellipse where the Earth would be closest to the sun and a line to the point on the ellipse where the Earth would be farthest from the sun." Mr. Johnston draws the lines with a ruler as the students watch.

Mr. Johnston's thinking: *Since the orbital paths of the planets are ellipses, there must always be a point where a planet is closest to the sun and another point when it is farthest from the sun. Mr. Johnston is hoping that the students will see this.*

Next, Mr. Johnston has the students observe pictures and drawings of the solar system from resource books and the Internet. Using these resources as well as their own drawings of the ellipses, the students

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make inferences about the time it takes for each planet to travel once around the sun. They reason that Neptune's journey must be the longest and Mercury's the shortest.

When the students have completed this stage of their investigation, Mr. Johnston projects a website onto the SMART Board that provides a simulation of the planets in their orbits. Oops! It appears that Pluto is still there. The class notices that. The students reason that it may take some time before newer, more current solar system models replace the older version. The website is still useful, however, because it shows the inner and outer planets as they orbit at their varying distances from the sun. As Mr. Johnston controls the animation, students notice that the Web page also has a chart showing how many Earth years it takes for each of the other planets to revolve around the sun. Mercury makes five revolutions in the time it takes the Earth to make one. This simulation provides the students with another model—a virtual model—of how planets orbit the sun. This virtual model is sometimes called a **simulation**.

The Teaching Ideas behind This Story

- Notice how Mr. Johnston engages the students in drawing first ellipses of the same size and then ones of all different sizes.
- Mr. Johnston offers labels for their images without precisely defining the terms *ellipse* and *foci.* The students will develop those definitions from their experience of drawing their figures.
- Mr. Johnston uses each opportunity to extend the students' thinking about the solar system. The ellipse drawings become a springboard for further research about the time it takes for planets to complete each revolution around the sun. Mr. Johnston enhances the students' understanding with the simulation website on planetary orbits. This provides an excellent reinforcement of the drawing activity.
- This orbiting-planets simulation also relates to NETS-S standards. The students:
  - "Use models and simulations to explore complex systems and issues."
  - "Collect and analyze data to identify solutions and/or make informed decisions," using "appropriate digital tools" (International Society for Technology in Education, 2007).

The Science Ideas behind This Story

- A **satellite** is any heavenly body that travels around another heavenly body. The planets are satellites of the sun. The moon is a satellite of the earth.
- The planets' orbits around the sun are elliptical (oval shaped). Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.
- An ellipse has no center. It has two foci or focus points. The sun is located in space at one focus of the planetary ellipses.
- The point in a planet's orbit when it is closest to the sun is called its **perihelion**.
- The point in a planet's orbit when it is farthest from the sun is called its **aphelion**.
- The time needed for a planet to make one complete turn or revolution around the sun is called its **year**.

Connections to the Next Generation Science Standards

- **NGSS DCI: 5-ESS1-2: Earth and the Solar System:** The orbits of Earth around the sun and of the moon around the Earth, together with the rotation of the Earth on its axis, cause observable patterns. These include day and night; daily changes in the length and direction of shadows; and different positions of the sun, moon, and stars at different times of the day, month, and year.
- **NGSS SEPs:** Students are engaged in *developing and using models* and *using mathematical and computational thinking*.
- **NGSS CCs:** Students recognized *patterns*, *cause and effect*, and *scale, proportion, and quantity*.

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Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- What is the difference between a center and a focus?
- What are some implications of the planets' changing distances as they orbit the sun?
- Do you think planets travel at uniform speed in their orbits? How would you gather evidence for the speed of planets?
- If you were a Martian, how old would you be? That is, what is your age in Mars years?

8-4 Shapes of the Moon

In the next science story, sixth-grade students have the opportunity to explore the sky and record their findings. They are seeking patterns, and their results become a model of the moon's orbit around the Earth.

SCIENCE STORY

Shapes of the Moon

In the early autumn, the students in a sixth-grade class in rural Maine have been exploring models of the solar system. They have shown an interest in learning how the moon, the Earth's satellite, appears different at different times of the month. One day their teacher, Ms. Hogan, tells them that each of them will begin keeping a *moon-phase journal*. It will give them an opportunity to observe part of the solar system directly, outside the classroom.

In this journal, she explains, they should record their observations of the moon over a period of six weeks. She gives them these general instructions:

- Search the sky on a daily basis.
- Keep daily records of your attempts to see the moon—whether you see it or not.
- When you do see it, include the following things in your journal:
  a. A description or drawing of what you saw.
  b. The time and the date.
  c. What you were doing at the time.
  d. Anything else you want to write down.
- Become more aware of when the moon is visible in the sky.
- Watch for changes in the moon's apparent shape, and try to figure out the sequence of these changes.

Ms. Hogan's thinking: Ms. Hogan believes the students can best learn about the moon's phases through direct research, but she wants to leave the precise format of the moon-phase journal open for the students themselves to decide. This open format, she thinks, will be especially useful for students who express themselves better through drawing than they do verbally.

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Over the next six weeks, the students observe the sky and record their data in both words and pictures. Once a week, Ms. Hogan checks their progress and inquires about any difficulties they may be having. At the end of the six weeks, she asks them to bring their journals to class so they can share their observations.

Excited, they arrive in the morning to find large sheets of paper taped to the chalkboards in the room. On each sheet a heading reads, "What We Found Out about the Moon." The students take markers and begin filling in the sheets with their observations, discussing them as they do so.

Ms. Hogan's thinking: *There are many ways to encourage the students to share their observations. Ms. Hogan thinks that this method will allow students who are not always comfortable speaking publicly to display their work.*

Here are some of the observations that the students write down for the class to see (reprinted by permission):

- Sometimes, when the moon is rising or setting, it looks yellowish or even orange.
- The moon looks bigger when it is rising or setting than when it is high in the sky.
- You can see the moon in the early morning and the late afternoon at some times of the month.
- You can't see the moon when the sky is very bright in the middle of the day.
- Sometimes you can see a very pale full moon in the sky early in the morning.
- Sometimes, when there is a crescent moon—like a sliver in the sky—you can see the rest of the moon faintly lighted.
- After the crescent moon gets bigger, you can see a half-circle moon in the sky.
- The moon gets bigger as you watch it until it gets to a whole circle—a full moon.
- The moon gets smaller each night after the full moon.
- When the moon is almost full, it is bulging on one side. Then when it starts getting smaller, it is bulging on the other side.
- As the full moon keeps getting smaller, you can see a half-circle moon again in the sky.
- Soon, this half-circle moon looks like a crescent again.
- Sometimes you can only see the moon during the daytime.

The Same Side of the Moon

In Ms. Hogan's class the moon-phase journals are not the end of the project. One day she brings in a carton of teacups and a box of apples. Each of the teacups has a handle on one side. She asks the students to work in pairs and gives each pair an empty teacup and an apple. She asks the students to imagine that the teacup is a model of the moon and the apple is a model of the Earth. The students turn the cup so that the handle is facing the apple. She instructs them to move the cup in a path around the apple, keeping the handle facing the apple at all times.

The pairs of students do this several times until they see that as the "moon" moves once around the Earth (revolves), it also rotates (turns) once on its own invisible axis. The students then model this process by walking around each other; the students who model the moon keep one elbow pointed toward the students who model the Earth. This activity helps students see that the moon always has the same side facing the Earth because it rotates or spins once during each revolution around the Earth.

Modeling the Moon Phases

The next step is for the students to create a slightly more elaborate model of the moon's phases as they observed them in the night sky. They use a volleyball to represent the moon, and they darken the room before they start.

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Ellen stands in the center of a large space, representing the planet Earth. Patrick, holding the volleyball, walks around Ellen, turning slowly as he goes to keep the same side of the volleyball facing her at all times. Johanna, representing the sun, stands to one side of the moon–Earth system with a strong flashlight, which she shines at the volleyball. As the volleyball reflects the light from the flashlight, these science ideas emerge:

- You can light only half the volleyball (moon) at one time because it is a sphere.
- As it moves around the Earth, only part of that lit half is visible from the Earth.
- The moon rotates once as it revolves once around the Earth.
- The same side of the moon is always facing the Earth.
- Different parts of that side of the moon receive light at different times in its journey.
- The shapes of the moon that we see in the sky are called *phases.*
- When we see the full moon, the entire side of the moon that faces the Earth is reflecting light.

By this time, the moon-phase journal and the following activity have led the students to formulate new questions. They wonder, for instance, about the yellow-orange color of a rising or setting moon; about the "halo" that sometimes appears around the moon; and why the moon appears bigger when it is low in the sky. These are complex issues, and the students explore them in resource books and on the Internet.

The Teaching Ideas behind This Story

- Giving students more than a month for the project allows them to observe the moon phases repeating themselves. It is another example of sustained inquiry. Besides leading to better understanding of the moon, this process helps the students give meaning to the notion of cycles in other natural processes and in their own lives.
- Although Ms. Hogan hopes the students will understand that the moon's phases repeat and are predictable, she does not give them this information in advance.
- The information the students gain from keeping a moon-phase journal establishes a foundation for the teacup–apple simulation and makes it possible to construct the volleyball model of moon phases. Thus, like Mr. Johnston's edible solar system, the journal is not just an end in itself but also the basis for further explorations. Models of all kinds are important for testing our science ideas.

The Science Ideas behind This Story

- Like the planets, the moon is visible because it reflects the sun's light. In other words, the light from the sun radiating outward in space in all directions bounces off the surface of the moon.
- The moon appears to have different shapes in the sky as it revolves around the Earth. These different shapes are called **phases of the moon** (Figure 8.3).
- It takes twenty-nine days for the moon to progress from one full moon to the next. This is the time it takes the moon to make one revolution of the Earth, and it is the same as the time it takes the moon to spin (rotate) once on its axis. Because the moon rotates once as it revolves, we see only one side of the moon from Earth.

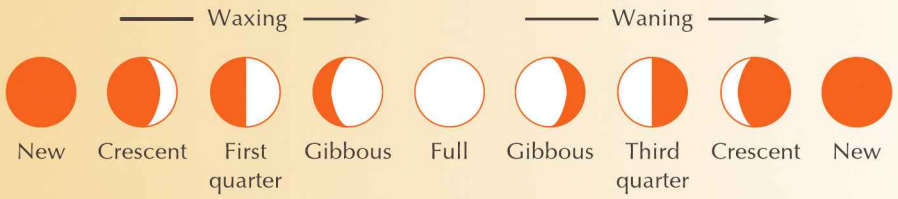

FIGURE 8.3 The phases of the moon in the northern hemisphere

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- As the moon moves around the Earth, different portions of its lighted side are visible on Earth because of the moon's position relative to the sun and the Earth.
- As the moon appears to get bigger in its progress toward a full moon, we say it is *waxing*. As it appears to get smaller after the full moon, we say it is *waning*.

Connections to the Next Generation Science Standards

- **NGSS DCIs:**
  - **MS-ESS1-1: The Universe and Its Stars:** Patterns of the apparent motion of the sun, the moon and stars in the sky can be observed, predicted, and explained with models.
  - **MS-ESS1-2: The Universe and Its Stars:** Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe.
- **NGSS SEPs:** The students were *developing and using models*; *analyzing and interpreting data*; and *obtaining, evaluating, and communicating information*.
- **NGSS CCs:** The students were examining *patterns* and looking at *systems and system models* while examining *scale, proportion, and quantity*.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- What other types of objects could be used to model moon phases in the classroom?
- What do you think is meant by "earthshine"?
- Have you ever looked at the night sky through strong binoculars or a telescope? What kinds of details do you think you would see that are not observable with the naked eye?
- Imagine keeping a moon-phase journal in South America. What might the images look like?

8-4a Using Moon-Phase Journals

asteroid
A tiny chunk of planet-like material that moves around the sun. Between Mars and Jupiter, there is a belt of several thousand asteroids of different sizes.

ellipse
An oval shape with no center but with two points of reference called *foci*. Planets travel in elliptical orbits around the sun, which is located at one of the foci of the orbits.

focus
One of two points (foci) used to construct an ellipse.

simulation
A computer program, virtual construction, or other procedure that imitates a real-world experience.

Keeping a moon-phase journal has many similarities with keeping a science journal. As we noticed earlier in this book, journaling invites students to observe nature in some way and then reflect on their observations. The moon-phase journal is most appropriate for students in fifth grade or higher, since this exercise requires that they be outside frequently at night. Although on some nights they may be able to see the moon through a window, it is important to alert families to this project and solicit their support and cooperation.

During some parts of the month, the moon may not appear until after the students' bedtimes. Weather can also interfere with viewing. To keep the students from feeling frustrated, it helps to ask them, as Ms. Hogan did, to record all of their experiences, even the unsuccessful ones. And because the moon's period of revolution is about four weeks, it is important to define the project's time period as longer than four weeks; five or six weeks is a good idea so students can observe the repetition of the cycle.

It is my experience that students of all ages, from fifth grade up, take pride in their moon-phase journals. I have even used this project in my teacher education classes, where the preservice teachers become equally enthusiastic about the project. I explain that I hope the experience will enhance their confidence in their abilities to observe. I also make a point of giving them the freedom to

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satellite
A natural satellite is any heavenly body that travels around an-other heavenly body. The moon is a satellite of the Earth, and the Earth–moon system is a satellite of the sun.

perihelion
The point in a planet's orbit when it is closest to the sun.

aphelion
The point in a planet's orbit when it is farthest from the sun.

express and present their observations in any way they choose. "Think of the task as an adventure," I tell my students. "What can you find out about the moon simply by observing it on a regular basis?" Many are astonished to realize that just by looking closely, they can discover a great deal about a natural object that they have seen all of their lives.

When students bring their moon-phase journals to class, I find it useful to have them share the journals with each other before recording their observations. As they review and discuss all the information they have gathered after weeks of keeping a journal, the science ideas really begin to emerge.

If you start a moon journaling project with your students, you'll also find that it offers one other advantage. It will allow you to learn about some of your students' hidden talents. The artists and the poets in particular will have an opportunity to show their creativity.

8-5 Making Models with Engineering Design

year
The time needed for a planet to make one complete turn or revolution about the sun.

phases of the moon
The various aspects of the moon as seen from Earth, such as the full moon and new moon. These phases reflect changes in the amount of the lighted surface of the moon that we can see from Earth.

Now let's examine how an eighth-grade physical science teacher approaches the study of atoms—a subject that lends itself to model building because you cannot see an atom using ordinary optical microscopes. Even using scanning tunneling microscopes, you can map out the images of atoms but not really see them in the visual sense. As you will learn, however, there is a great deal of evidence about what structures make up an atom, and scientists use those data to build models.

As you read the following story, be prepared for the Atom Design Challenge. Design challenges are part of integrating engineering technology into science education. The teacher uses a design challenge to engage the students in designing and constructing their own model of an atom. Notice how much research is needed before design and model building can begin.

SCIENCE STORY

Making Models of Atoms

Ms. Murray is an eighth-grade teacher in a middle school in a small suburban community. The students in eighth-grade science explore physical science, addressing topics in chemistry and physics. It is the beginning of the school year, and Ms. Murray is concerned because the topic of atomic structure, which the students will tackle this term, involves very abstract concepts. After researching the best way to introduce concepts related to the structure of the atom, she has decided to explore the history of atomic theory and then let students use their knowledge about atoms to design and construct models of an atom of a particular element.

I am going to be present as a visitor, but before the class begins, I have a chance to ask Ms. Murray what she hopes the students will get out of their unit on atomic structure. She mentions a number of basic concepts about atoms: that an atom is the smallest particle into which an element can be divided and still have all the properties of that element; that an atom is composed of a nucleus and electron clouds; that the atomic nucleus contains protons and neutrons; and so on. But she also hopes, she adds, that "the students will be able to understand the difficulty that scientists had developing the atomic theory, considering that they only had a mental model to work with. I hope they will understand that atomic theory may not be completely correct, and that is why there are always changes to atomic theory over time."

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My thinking: I am impressed that Ms. Murray views atomic theory as a fluid, constantly evolving collection of ideas.

As the atomic structure unit begins, Ms. Murray distributes newspaper photos and magnifying lenses. She asks students to make observations of the photos using the magnifiers and record their observations in their science notebooks. After a few minutes she says, "What did you notice?" A few students respond that they saw small dots. "Now try to see the dots without the magnifying lenses." Students say they cannot. Ms. Murray then asks if there are other examples of objects that are made up of small parts that can't be seen with the naked eye. Students' answers are varied. Brian says, "Molecules." Nat says, "Pigments," and another student says, "Atoms." Heather adds, "Cells are another example."

Ms. Murray now describes atoms as the building blocks of all matter. She explains that just like cells, which are the building blocks of living things, atoms cannot be seen with the naked eye. She then asks students to record the following question in their notebooks and think about an answer: "How many atoms can fit in a period at the end of a sentence?" Immediately, hands fly up. "What size period, one on the blackboard or one on a sheet of paper?" asks one student. Ms. Murray says that their questions are excellent, and she instructs them to think about a period at the end of a sentence printed in a twelve-point font. She suggests that they take out one of the prior handouts to examine the size of the periods.

After a few minutes, Ms. Murray asks for volunteers to offer their responses. Hands again fly up. The answers, which Ms. Murray writes on the board, range from 1 million to 100 trillion. All the students are eager to know the actual answer, so she informs them that there are roughly 1 trillion atoms in a twelve-point period. Wanting them to see the number, she writes it on the board. One student says, "Wow, a *penny* must have a lot of atoms." Ms. Murray gives the number of atoms in a penny in scientific notation by saying, "Yes, there are two times ten to the twenty-fourth power atoms in a penny." She then writes that number on the board as well: 2,000,000,000,000,000,000,000,000. For homework, Ms. Murray asks the students to come up with their own estimates for the number of atoms in other objects smaller than a penny, using the period and the penny as reference points.

Exploring the History of Atomic Theory

The next class begins with six trays of materials set up around the room. Each tray contains information about a different scientist, including various books and cards that list addresses of websites. Ms. Murray tells the class, "Since atomic theory has been around for over 2,500 years, it will be good to explore its history." The six scientists are Democritus, John Dalton, J. J. Thomson, Ernest Rutherford, Niels Bohr, and Maria Goeppert Mayer. She asks the students to work in research teams. Each team will use one tray of information to design and construct a poster illustrating the following information:

- The time period in which the scientist lived
- The major discovery the scientist made regarding the atom
- Whether the scientist's theory is still accepted

Using its poster as a teaching tool, each group will teach the rest of the class about that scientist and that portion of history. Students get right to work on their projects, and they continue the next day. Ms. Murray visits each group to check its progress and make suggestions.

My thinking: It seems that each group of students will become knowledgeable about a specific atomic scientist on their own terms. They will decide what data to include. It will be interesting to see what the work reveals. I am also struck by how Ms. Murray has carefully constructed each group, mixing gender, ability, and ethnicity.

When the posters are ready, Ms. Murray calls the groups in chronological order, from the earliest scientist to the most recent. As each group presents its scientist, a new piece of the history of atomic theory unfolds. The posters remain on the board in the order of the scientists' discoveries, thus creating a colorful timeline of the history of atomic theory. Halfway through the presentations, one student blurts out, "Oh, I get it, the scientists build on each other." Ms. Murray also has the students describe the big ideas that emerged in each period. The students' comments are summarized in Table 8.3.

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TABLE 8.3 Nuclear Theory Chronology as It Emerged in Ms. Murray's Class

Date	Scientist	Experiment or Theory	"Big Idea" of the Time Period
530 B.C.	Democritus	Material is made of atoms that cannot be split into smaller particles.	All matter is made up of atoms too small to be seen.
1808	John Dalton	All atoms of any element are the same. Atoms of different elements are different.	Modern atomic theory: every element is made of atoms.
1897	J. J. Thomson	Cathode-ray experiments reveal existence of negatively charged particles.	Inside the atom are negatively charged particles called electrons.
1911	Ernest Rutherford	Alpha particle experiments show that atoms have a lot of empty space.	The atom has a positive nucleus, with electrons orbiting around it.
1922	Niels Bohr	Electrons emit energy only when they change energy levels.	Electrons travel in specific orbital "shells" around the nucleus. Each shell represents a discrete energy level.
1963	Maria Goeppert Mayer	"Magic numbers" of nuclear particles suggest a shell model of the nucleus.	Particles in the nucleus are also arranged in "shells." Protons and neutrons exist in pairs in the nucleus, and this arrangement gives different atomic nuclei different degrees of stability.

Ms. Murray then asks the students how many scientists they think actually contributed to the concept of the atom. Several students respond that hundreds did. "Why," says Ms. Murray, "aren't they up on the timeline?" One student answers, "Maybe their discoveries were small, but they made it possible for the big discoveries to be made." Finally, Ms. Murray asks if the atomic theory is 100 percent accurate. The class discusses how the theory has constantly been modified and probably will be modified more in the future. The students are now ready to experiment on their own and create their own mental models.

My thinking: I am struck by how explicit Ms. Murray is making the nature of science and scientific activity. She also illustrates that as one scientist's work was built on by the next, new ideas replaced older ones, and this took an exceedingly long time. Although many people feel it is important to teach these concepts in middle school, teachers do not always see their relevance. Ms. Murray manages to embed these notions in the discussion of atomic structure.

Mystery Boxes

The following day, students have a double period of science, and they are asked to perform experiments on "mystery boxes" to determine the contents of each box. Ms. Murray wants the students to develop a mental model of something that cannot be seen but can be known through evidence. This process, she hopes, will model the way in which scientists gather data about atomic particles they cannot see.

Each pair of students receives a sealed box containing various items. They shake the box, listen, and use all their senses to try to determine the number of objects in the box and the identity of each. (The mystery objects include jacks, keys, marbles, small pencils, erasers, dice, and pennies.) Ms. Murray has the students record their procedures, their reasoning, and their answers. After the students present their

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results to the class, they open the boxes and are surprised at how many objects they inferred correctly. This success builds their confidence in their abilities to use their senses and their reasoning skills. Ms. Murray and the class then relate the mental models they have made of their boxes to the scientific models that evolved, and are still evolving, about the atom.

Discussing the Nucleus

The following day, Ms. Murray asks the students if they have ever heard the word *nuclear* before. They certainly have. The students mention nuclear fission, nuclear bombs, nuclear power, nuclear warheads, and nuclear power plants. Ms. Murray wonders, "Where do you think the word *nuclear* comes from?" A few students say it comes from the word *nucleus.* One student mentions that a nucleus is in a cell, while others say that it is part of an atom. Together the students review Rutherford's discovery of the nucleus of the atom and some of the other discoveries from their presentations. They talk about the nucleus being within the atom, positively charged, very dense, and made up of particles. The students recall that the nucleus is composed of protons and neutrons, and on the basis of the particles' names, they deduce that protons are positively charged and therefore neutrons must be negatively charged. At this point Ms. Murray helps them to explore other ways of interpreting the word *neutron,* and they realize that they can associate it with the word *neutral.* The students then arrive at the (correct) notion that a neutron has no charge.

They go on to discuss what happens when two like charges are near each other. Using magnets as a reference, they conclude that two likes would repel, so Ms. Murray asks them, "What happens in the nucleus? If protons have like charges, wouldn't they repel each other and break apart the nucleus?" She gives the students time to think about this question and to come up with their own theories. Ms. Murray reassures them that she is not interested in the right or wrong answer but in their thoughts. She tells them, "Scientists always come up with theories that may be incorrect or partially true. It is okay if you are not sure." She lets them know that they can draw pictures to help them visualize their ideas, and she gives them ten minutes to prepare their answers.

When the ten minutes are up, Ms. Murray instructs the students to move their chairs into a large circle. She brings out a small beanbag frog and explains the rules of the discussion: You can talk only if you have the beanie frog, and you can throw the frog only to someone who has his or her hand up. In addition, if you can answer only part of the question, it is okay to pass the frog to someone else.

The students toss the frog around and discuss their theories. Kate says that the attraction between the negative charges of the electrons and the positive charges of the protons causes the nucleus to stay together. Brian says that he too considered this idea, but "then I found a flaw with my theory. If the electrons were attracted to the protons," he says, "they would pull the protons away from the nucleus." Isaac has a totally different theory: that perhaps the neutrons prevent the protons from repelling. He imagines the nucleus as a sandwich: proton–neutron–proton. Jamie says that she can understand how the neutrons play that role because there is no other known reason for their existence in the nucleus.

> ***My thinking:*** *Ms. Murray's use of the frog toss to engage students seated in a circle gives students the responsibility for managing their own participation. This is an effective way to get students talking about their theories.*

Ms. Murray compliments the students on their thinking and then tells them about what scientists call the *strong force,* a force that keeps the nucleus together. This force may derive from the neutrons, but scientists do not yet know exactly how it works. She then invites the students to create their own pictures of what the atom may look like. The students have enough evidence from their historical research to understand that protons and neutrons are in the nucleus and that the electrons move in different ways around the nucleus. When the students have made their drawings, Ms. Murray asks whether there is just one way to draw an atom. The students say no, because no one has ever seen the inside of an atom. She draws a diagram on the board but explains that this is only one way to draw the atom.

The Periodic Table

The following week, Ms. Murray introduces the class to the periodic table of the elements. She shows how the atomic mass and atomic number are associated with each symbol in the table. After she models the

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element helium by indicating its two protons and two neutrons in the nucleus of the atom, Ms. Murray asks the students where to put the two electrons. The students all appear to understand that the electrons go outside the nucleus. After discussing the electric charge on the protons and the neutrons, Ms. Murray introduces the theory of electron clouds in the following way.

The class reviews what Bohr said about the way electrons move in orbits, and students discuss whether that theory is still accepted. They think not, because they remember hearing about electron "clouds." Ms. Murray then places a fan in front of the room and tells them to keep their eyes on one of the blades. The challenge is to follow that blade when the fan begins to move.

Ms. Murray turns the fan on the low setting, and within a few seconds a voice calls out, "I lost it." I am assisting with the fan, so I ask students if they know roughly where their one blade is. "In that circle," Shana says. Ms. Murray asks, "Does anyone know *exactly* where the blade is?" The class answers, "NO!" She explains, "Just like you kind of know where the blade is, but not exactly, scientists kind of know where electrons are, but not exactly. That is why scientists talk about *electron clouds*." On the board diagram she draws a broad space around the electrons and shades it in. "Scientists think that electrons are somewhere in this area, but they don't know exactly where."

Ms. Murray then asks the students if they have peeled an onion before. Hands shoot up. She takes out an onion and asks whether it will be hard or easy to remove the top layer. "Easy," the class agrees, so she removes it. When she asks about the next layer, the students are a little unsure. She removes that layer, and a few students say the task was a little harder. When she goes on to ask about the third layer, the students say it will be harder to remove, and indeed it is.

Now Ms. Murray makes an analogy between the onion layers and electrons in the atom. The class spends a good deal of time discussing electron shells and electron clouds and trying to make sense of tiny particles moving very quickly at different distances from the nucleus of the atom. The onion proves a helpful tool. In the following days, the class examines the periodic table and the numbers in each of the table's boxes. Students then make a model of the table using fruits and vegetables. Their understanding of the atoms of each element is really beginning to grow.

The Atom Design Challenge

In week three, Ms. Murray poses a design challenge. She hands each student a booklet titled "Atom Design Portfolio." On the booklet's face is a page that states the challenge, as shown in Figure 8.4. In groups, students are supposed to build their own models to depict the atom of a particular element. The booklet contains various sections to guide students through the process: Selecting Your Element, Research, Resources, Brainstorming, Sketches of Possible Solutions, Selecting the Best Solution, Reflecting on the Process, and Evaluation. Ms. Murray explains each of the specifications listed in Figure 8.4 and addresses the importance of being creative and original. The students are excited and full of questions. Ms. Murray explains the materials she will bring (including balloons, markers, clay, rubber bands, and Popsicle sticks), and students generate a list of common materials they can bring from home (bubble wrap, string, felt, milk cartons, egg cartons, Styrofoam, and so on).

To begin the project, Ms. Murray has each student individually choose two possible elements to explore and list a reason why each would be interesting. Then the students meet as groups to discuss their choices, agree on a single element to use for the project, and begin to discuss the most important questions. The next class period is spent in the library, where the students use books and the Internet to research answers to their questions about their element.

The following day, the students begin to brainstorm their designs for their atoms, incorporating a lot of the data from their research. For instance, the group designing an atom of sulfur wants to use yellow materials. After the day of brainstorming, Ms. Murray and the students together develop a *rubric* for evaluating their final solutions (Table 8.4). (You will read more about rubrics in Chapter 13.) Many of the students want to know what they need to accomplish to receive a perfect score; they are not interested in receiving anything less.

Each group is required to draw three possible models for their design project, choose one, and then have the final sketch approved by Ms. Murray. She wants to make sure that when construction begins, the students will know where to start. Some groups come to agreement more readily than others. Ms. Murray

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Atom Design Portfolio

Name: _____

Group Members: _____

Problem Statement: Your challenge is to build a model of an atom that creatively and accurately depicts an element.

Specifications:

- The element chosen must be between boron and argon on the periodic table.
- Your model needs to depict the atom of that element accurately, using the correct numbers of the three major subatomic particles.
- The model should be creative and original.

Constraints:

- The model can be no larger than 1 m x 1 m and no smaller than 15 cm x 15 cm.
- The model needs to stand on its own.
- The only materials that can be used are those found in class.

When selecting an element, explore one that you want to learn more about. Remember that it must be between boron and argon on the Periodic Table.

FIGURE 8.4 Cover sheet for the Atom Design Challenge

Professional Resource Download

actively participates in two of the groups that struggle to find consensus. Four of the groups need hardly any assistance from her at all.

My thinking: *When I ask one group why they have chosen the element boron, they all say, "Because we didn't know anything about it." I am impressed by this group's willingness to take ownership of their learning.*

Over four class periods, the students complete and decorate their models. Every day, the students come into class excited; the sense of pride they take in their work can be seen in their eyes and heard in their voices. A student in one of the groups says, "Ms. Murray, look at our project! Doesn't it look great?"

Ms. Murray's thinking: *Ms. Murray now believes she has accomplished something bigger than teaching the students about atoms. Her students no longer need her to tell them their work is great. They have gained confidence in it, in each other, and in their knowledge. She is very proud of them.*

When the students present their final design projects, they demonstrate their understanding of atomic structure as well as the specific uses of their elements. Overall, the class has built models of boron, carbon, aluminum, magnesium, phosphorus, and neon, and the models are quite different from one another. The neon group has used Popsicle sticks, beads, tape, paper towel rolls, and other materials to create a model of neon's ten protons, ten electrons, and ten neutrons. When they present this model, the students explain that neon is a colorless, odorless gas that is lighter than air and is used in neon lights. The students point out the two energy levels for neon's electrons and show how they twisted pipe cleaners around the sticks to represent electron clouds.

The boron group has used a white triangular Styrofoam base to hold a nucleus with five protons and six neutrons. Around the nucleus, fanlike blades represent boron's five electrons in two energy levels (Photo 8.4). The students are especially proud of these electron clouds. They talk about the scientists who discovered boron and share the fact that boron is used in pyrotechnics and flares to produce a green color. It has also been used in some rockets as an ignition source.

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TABLE 8.4 Rubric for Design Project

Category	Score	Description
Success of the solution	4	The solution solves the problem statement. Detail and design are excellent. Hard work and planning are obvious.
	3	The solution solves the problem statement, and the constraints and criteria are met.
	2	The solution solves the problem, but not all constraints and criteria are met.
	1	The solution does not solve the problem; constraints and criteria are not met.
Creativity of the design	4	The solution is unique; never or seldom has this design been formulated.
	3	The solution is functional but not unique.
	2	The solution is similar to a number of others; it may be a modification or interpretation of another group's solution.
	1	The solution has been copied from another group's.
Accurate measurement and calculation	4	Rulers were used appropriately to measure material throughout the process of planning and implementing ideas.
	3	Rulers were used appropriately during the implementation of ideas.
	2	Measuring devices were rarely used. Some mathematical calculations are incorrect.
	1	Errors in measurement are evident.

My thinking: I find it wonderful that the electric fan lesson carried over to this group's stunning model of electron clouds.

The Teaching Ideas behind This Story

- By examining historical scientific models, Ms. Murray gives the students insights into the nature of science and the role of historical, philosophical, and technological contexts in the development of scientific knowledge.
- Ms. Murray discards the rigid view of what an atom looks like in favor of a more open-ended (and more scientifically accurate) approach. By doing this, she allows her students to develop a much deeper knowledge of atomic structure than if they had merely studied the usual pictures and built conventional models.
- To make abstract concepts concrete, Ms. Murray uses her own everyday models—the electric fan and the onion.

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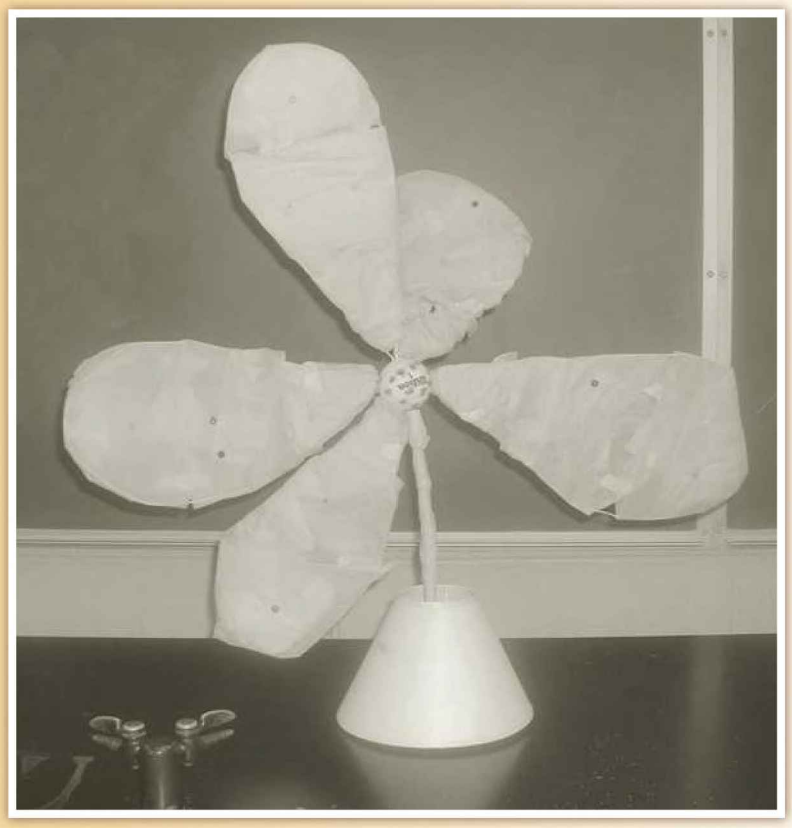

Janice Koch

PHOTO 8.4 The model of a boron atom made by students in Ms. Murray's class.

- In a **design challenge**, students plan, research, design, and construct solutions that lead to a product or a process. Essentially, design is the technological counterpart of the science-as-practice process. Today we understand that all students should develop abilities of technological or engineering design. Students' work with scientific investigations can be complemented by activities in which the purpose is to meet a human need, solve a human problem, or develop a product. Students should make and compare different proposals in the light of the criteria they have selected. "They must consider constraints—such as cost, time, tradeoffs, and materials needed—and communicate ideas with drawings and simple models" (National Research Council, 1996).

The Science Ideas behind This Story

- As you saw in this chapter, models are important in scientific research, both in formulating hypotheses to be tested and in describing scientific phenomena.
- Science has revealed a great deal about the structure of the atom. Scientists are now conducting experiments to explore the structure of the nucleus and the forces that hold it together.
- Atoms are so small that we cannot see them with an ordinary microscope. In the past three decades, however, new types of microscopes, such as the atomic force microscope, have allowed us to see atoms and investigate their properties.
- Atoms of different elements have different properties and differ in size.
- All atoms are electrical in nature. They have positively charged particles called **protons** in their nuclei and have negatively charged particles called **electrons** surrounding the atomic nucleus. The number of protons in a given atom is equal to the number of electrons; hence, atoms are electrically neutral.

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- In addition to protons, the atomic nucleus contains **neutrons**, particles without an electrical charge.
- The mass of a proton is equal to the mass of a neutron. Electrons have only about 1/1,800 of the mass of a proton or neutron.
- Electrons revolve around the nucleus in distinct energy levels or "shells." Rather than call these paths *orbits*, scientists today prefer the term *orbital*, which refers to the wavelike function of the electron. Electrons exist both as particles and as waves. The various orbitals are at different distances from the nucleus of the atom.
- Because we can never know the exact position of an electron in its orbital, it is useful to think of these particles as moving in **electron clouds**, general areas where they may be found. The densest part of the cloud is the area where the electron is most likely to be.
- Each electron cloud or energy level has a maximum number of electrons that it can hold. The first major energy level has a maximum of two electrons; the second, a maximum of eight electrons; and the third, a maximum of eighteen electrons.
- The farther away the electron is from the atomic nucleus, the more readily it can leave the atom.

Connections to the Next Generation Science Standards

- **NGSS DCIs:**
  - **MS-ETS1-1: Defining and Delimiting Engineering Problems:** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful.
  - **MS-ETS1-2 and MS-ETS1-3: Developing Possible Solutions:** There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.
  - **MS-ETS1-4: Developing Possible Solutions:** A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.
  - **MS-PS1-1: Structure and Properties of Matter:** Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from 2 to thousands of atoms.
  - **MS-PS1-2 and MS-PS1-3: Structure and Properties of Matter:** Each pure substance has characteristic physical and chemical properties that can be used to identify it (for any bulk quantity under given conditions).
- **NGSS SEPs:** Students were *asking questions and defining problems*, *developing and using models*, *analyzing and interpreting data*, *using mathematical and computational thinking*, and *constructing explanations and designing solutions*.
- **NGSS CCs:** Students were examining *structure and function*, *patterns*, and *cause and effect*.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- How does Ms. Murray's atomic structure unit differ from conventional ways of teaching atomic theory?
- How do the groups of students in Ms. Murray's class demonstrate what we know about how students learn?
- What other middle school science topic lends itself to a design challenge?
- Which parts of this science unit might be adapted for collaborative teaching with a history teacher? With an English teacher?

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Nanoscale Science and the Study of Atoms

You have probably heard about *nanotechnology*, the design and production of structures, devices, and systems on the scale of an atom or molecule. The term is derived from *nanometer*, meaning one-billionth of a meter. This technology is behind advances in products ranging from computer processors to sunscreens to tennis balls, and there is tremendous potential for nanoscale robotics—for instance, little machines that might swim through your blood vessels to attack disease. Not surprisingly, educators have begun developing science units that explore nanotechnology. **Nanoscale science** refers to inquiry-based activities designed to help middle and high school students explore the unique properties and behaviors of materials at the nanoscale (Jones et al., 2007).

In exploring the nanoscale with their students, teachers face the same problem that Ms. Murray did: how to guide students in forming a mental model of something so small they can't see it. In one exercise developed by nanoscience teachers (Jones et al., 2007), the teacher writes the number one thousand on the board (1,000) and asks students how much larger one billion is. This question produces many different responses. The answer is actually one million: A billion is a million times larger than a thousand. Then students are asked how big a container would need to be to hold one billion golf balls. When students investigate this question, they learn the golf ball is one billionth the size of approximately 400 classrooms (assuming each classroom is 10 meters by 10 meters by 3 meters). Holding a billionth of these classrooms' volume in their hand introduces the students to the incredible scale of nanotechnology, a billionth of a meter! If you filled the average bathtub with table salt, there would be approximately a billion grains of salt. One grain of salt in that tub is a billionth.

As older students study the structure of the atom, they will be exposed to nanoscale science and to a new frontier in which scientists can manipulate materials on the atomic scale and produce new structures that could serve society in many different ways. Here are some resources for lessons and activities related to nanoscale science:

- Jones, M. G., Falvo, M. R., Taylor, A. R., & Broadwell, B. P. (2007). *Nanoscale Science: Activities for Grades 6–12*. Arlington, VA: NSTA Press. Twenty investigations help students explore the properties and behavior of materials at the nanoscale.
- *Nanoscale Science*. This site from the National Nanotechnology Infrastructure Network is a guide to understanding the tools used in nanotechnology and exploring the images that these tools can produce. There are lessons and activities that may be appropriate for high school and advanced classes in middle school. http://www.nnin.org/education-training/k-12-teachers/
- *NanoScale Science Education*. This website includes links to activities for elementary and middle school grades. http://www.ncsu.edu/project/scienceEd/

8-6 Engineering Design Technology

design challenge
In design technology, a specific problem that students are asked to solve by designing and constructing a product or an optimal solution.

proton
A positively charged particle in the nucleus of an atom.

The design challenge that Ms. Murray posed for her students leads us to the subject often known as **design technology** or *engineering design*. It requires students to identify and state a problem, design a solution, implement a solution, and evaluate the solution.

Think of it this way: As part of science as practice, students engage in the exploration and analysis of natural phenomena. They manipulate materials, plan experiments, make observations and inferences, and try to find answers to problems that they pose. As part of design technology, students plan, research, design, and construct solutions that lead to a product or a process. Like science practices, engineering practices are recursive and iterative processes—trying one solution and, on the way to it, finding another.

When we add engineering practices to science practices, we ask students to solve a problem—often called a design challenge—that requires them to use

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electron
A negatively charged particle found in the atoms of all elements. Electrons revolve around the nucleus of the atom in different orbitals or "shells"; each shell represents a distinct energy level. Each electron is thought to be a particle of negative electricity.

neutron
A particle with no electrical charge found in the nucleus of an atom.

electron cloud
A term for the general area occupied by each "shell" or energy level where electrons orbit the nucleus of an atom. The metaphor of a "cloud" emphasizes the fact that we cannot know exactly where an electron is at a particular time; we just know that it is somewhere within that general area.

nanoscale science
Inquiry-based activities designed to help middle and high school students explore the unique properties and behaviors of materials on the scale of an atom or a molecule.

design technology (engineering design)
The technological counterpart to the science-as-inquiry process. For students, the design process typically involves solving a problem by constructing a product that meets a set of established criteria, called specifications.

some of the scientific and/or mathematical ideas they are exploring through their scientific investigations. The solution typically involves constructing a product or process that meets stated specifications or *criteria* and that is built according to specific *constraints*.

8-6a Design Portfolios

As you saw in Ms. Murray's class, design projects often use a portfolio as a tool to assist students in the design process. Design portfolios include the problem statement, specifications or criteria and constraints, and several other sections.

From the sound of the term *engineering design*, you may think it applies mostly to students in middle grades and high school. But the abilities of technological design are developed at all grade levels. What might a design challenge for younger students look like? How do they define problems and seek solutions?

Think back to the story of liquids and density in Chapter 7. The liquid "toys" that the fifth graders constructed are another example of design technology. Design challenges are one more way to apply the core concepts in science to another context.

In the next chapter, fourth graders are studying electrical circuits. Students in third or fourth grade often read the classic children's book *Stuart Little* by E. B. White (1945), a story about a family whose younger son appears to be a mouse. Imagine a design challenge in which the students are asked to design and construct a four-room home for this beloved mouse, and the criteria require a light for each of the rooms. Stuart the mouse stands two inches tall, so mathematical measurements involving scale are required to construct the house. Knowledge of how to wire the ceiling lights and install a switch helps students apply their understanding of electrical circuits. The students would then evaluate their solutions and most likely would learn a great deal about series and parallel circuits as well as about larger themes of proportion and scale. As you will see, Ms. Travis's class in the next chapter begins to see the applications of their understanding of electrical circuits to their construction of lighted "shoebox" rooms.

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CHAPTER 9
Beyond the "Science Kit"

Next Generation Science Standards

- **Crosscutting Concepts:** 2, 4, 5
- **Disciplinary Core Ideas:** 4-PS3-2, 4-PS3-3, 4-PS3-4
- **Science and Engineering Practices:** 1, 2, 3, 6

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 9-1 Critique the rigid use of the electricity kit materials.
- 9-2 Analyze how the electricity materials can be used to enhance student learning.
- 9-3 Examine how the shoebox house design project employs science and engineering practices.
- 9-4 Understand what is meant by science PCK and its connection to the 5e learning cycle.

Reflection To Think About:

- Have you ever explored the inside of a flashlight?
- Does your home have fuses or circuit breakers?
- Why does faulty electrical wiring cause fires?
- How many atoms can fit on the period at the end of one of these sentences?

People often use the word *energy* in daily conversation when they refer to not having enough energy or turning off the light to save energy. Yet, in spite of this ready connection to everyday life, energy remains an abstract concept for students because it is not a concrete substance with easily measurable properties in the way that matter is. Yet energy is a fundamental concept in the study of science.

Energy exists in many forms, and comprehending that one form of energy may be transformed into another requires a great depth of understanding. Elementary school students typically explore four forms of energy: sound, light, heat, and electricity. Their understanding deepens gradually as their exposure to these concepts increases, until by middle and secondary school, students can deal with the fairly abstract concepts of energy measurement and transformation. Some of the disciplinary core ideas that are the foundation of the study of sound, light, heat, and electricity include the understanding that the faster an object is moving, the more energy it possesses, and that energy can be moved from place to place by moving objects or through sound, light, and electrical currents.

Since energy is complex science idea, you probably think that many students develop alternative conceptions about it. You're right, as you'll see when you read the stories that follow. But this chapter also focuses on another type of alternative conception or misconception—one that exists in science education itself. It is found among teachers, administrators, creators of curriculum materials, and many others. This misconception relates to the thinking that there is a need for a specific box of materials and step-by-step instructions in order to do science with students. This is plainly not so! To do science with children and young adults, we often need materials, a good plan, an open mind, and a desire to learn what the students are thinking about the investigation at hand.

9-1 The Electricity Kit

In the following two stories, we examine the ways in which two fourth-grade classes explore the beginning of a unit on electricity. Both teachers have been given a typical science "box," that is, a kit of materials to use with their students. The box has arrived complete with specific instructions for the teacher and little booklets for the students. As you read, think about the nature of scientific activity in these two classes. Look for moments when authentic investigations are taking place. Ask yourself: "In which class would you rather be to learn about electricity?"

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SCIENCE STORY

Using the Batteries, Bulbs, and Wires Kit

Let's visit Ms. Stone's fourth-grade classroom in a Midwestern suburb. The students are about to begin a unit on electricity, and Ms. Stone is excited. The school district has just received several electricity kits from a commercial manufacturer. Ms. Stone is pleased that she can use these new materials to teach the unit on electricity.

The night before the unit begins, she reads the kit's "Instructions to the Teacher" and prepares her lesson. When she examines the contents of the science kit, she finds packages of D-cell batteries, battery holders, small 1.5-volt bulbs that look like flashlight bulbs, holders for the bulbs, and spools of thin wire labeled "bell wire." The kit also includes several wire strippers and switches. Following the directions in the kit, Ms. Stone cuts 30-centimeter strips of bell wire and uses the wire strippers to remove the plastic insulation from the ends of each strip. With small self-sticking letters, she then labels one end of each wire strip "A" and the opposite end "B."

The next morning she explains to the students that they are going to begin the electricity unit. But first, they need some definitions. She has arrived early to write three definitions on the blackboard, which she now asks the students to copy into their notebooks:

- An *electric circuit* is a continuous pathway for an electric charge or current to follow.
- A *series circuit* is a simple circuit in which the flow of electricity has only one path.
- A *parallel circuit* is a circuit where the flow of electricity has more than one path from the same power source.

Ms. Stone reads the definitions aloud and goes over the words. Quietly the students copy these terms into their notebooks.

> ***Ms. Stone's thinking:*** *Ms. Stone believes that the students need the vocabulary in order to carry out the investigation meaningfully. She believes in giving the meanings up front, before the students begin the exploration.*

Ms. Stone asks the students to get into their science groups of four. Each group, she explains, will get four bulbs, two batteries, four bulb holders, and two battery holders. Each group will also receive seven stripped wires, each 30 centimeters long, with the ends labeled "A" and "B." One end of each battery holder is labeled "B," and the other end is labeled "A." She explains to the students that they are *not* to touch the materials until she gives them instructions.

When all the materials are distributed, Ms. Stone begins. "Now, will one person in the group take the batteries and place them in the battery holders? Next, another person should gently screw each bulb into the bulb holders."

The students do as they are instructed. Then Ms. Stone continues, "Does everyone see that one end of the battery holder is marked "A" and one end of the wire is marked "A"? Okay, take turns as we follow the next steps. Attach the end of the wire marked "A" to the end of the battery holder marked "A" by putting the wire through the loop and twisting to make good contact. Now repeat what you just did with another wire, only this time take the end marked "B" and loop it through the end of the battery holder marked "B."

"Now you should have one battery that has two wires coming from it, one from each end," says Ms. Stone as she holds up a sample of what she means. The students are fidgety, especially those who are not working directly with the materials at that moment. *Why do you think the students are restless?*

"The next thing we are going to do," Ms. Stone continues, "is to connect the end of the wire that has a "B" on it to one side of one of the bulb holders. . . . Then take another wire and connect the end marked "A" to the other end of that bulb holder. . . . Now take the end of that wire marked "B" and connect it to a second bulb holder. . . . Then take the "A" end of the other wire that is attached to the battery, and connect it to the other side of the second bulb holder."

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Ms. Stone talks slowly and waits for the students to complete each step before proceeding with the next step. Finally, the bulbs light!

Ms. Stone's thinking: *Ms. Stone is pleased that the students have followed the directions well. She notices that every group's bulbs worked.*

"Okay," says Ms. Stone. "You have made a simple series circuit. Let's look at the definition on the board." The students listen as Ms. Stone reads the definition again. They are instructed to draw their series circuit and label it in their notebooks.

After Ms. Stone checks their drawings, she continues: "Now we are going to make a parallel circuit. This is a little more difficult, so you have to listen carefully." She proceeds in the same manner with direct, step-by-step instructions, which the students follow until the bulbs light. Once more, all the groups get the same result.

"This is called a parallel circuit," Ms. Stone explains. Together, she and the class read over the definition of a parallel circuit.

"Tomorrow," Ms. Stone tells the students, "we will use our series circuit to test for materials that carry electricity."

9-2 The Electricity Kit—Revisited

SCIENCE STORY

Revisiting the Batteries, Bulbs, and Wires Kit

Ms. Travis is a fourth-grade teacher in another school in the same school district. She is working with the same materials as Ms. Stone—with one difference. She has requested funds from the fourth-grade science budget to purchase twelve flashlights and twenty-four C-cell batteries, two per flashlight. She assembles all of the flashlights with their batteries. When the students enter the room the following morning, she invites them to form science groups of four.

Before starting the activity, however, Ms. Travis asks the students what they would purchase if she asked them to go to the supermarket and pick up a pound of electricity. The students call out different answers. One student says she would buy a pound of light bulbs. Another says he would buy a pound of batteries. Ms. Travis listens and asks them why they made those choices. "Is it the same to say that light bulbs *are* electricity," she wonders aloud, "as it is to say that light bulbs *work on* electricity?"

Ms. Travis's thinking: *Ms. Travis knows that students often think of the materials that produce or carry electricity as being the electricity itself. This alternative conception is common because electricity, a form of energy, does not have mass or volume like matter. Ms. Travis is trying to bring out prior ideas of this sort as the students begin the electricity unit.*

The students listen carefully to Ms. Travis's question. One student remarks that you can't really buy a pound of electricity because it isn't a real thing. Ms. Travis prompts, "Can you say more about that?"

"Well," the student continues, "you can't really hold electricity in your hand, but it can give you a shock." Ms. Travis invites others to think about that.

She then shares the following idea: "We know that anything that has mass and takes up space is matter. So if electricity is not matter, what is it?" This class knows she means "energy" because they have spent weeks studying heat energy. But it is important to Ms. Travis to remind the students again that energy is more difficult to "grasp" than matter because we cannot hold it concretely in our hands.

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Now they are ready to begin the activity. She explains that she would like them to explore some flashlights. "Take these flashlights apart; take out the inside parts," she requests as she distributes two flashlights to each group of four students. "It is better to work with one partner for this exploration," she adds. "How many of you have opened and explored flashlights before?" About half the students raise their hands.

"Girls and boys, you will notice that the top unscrews and then several pieces come out, including the bulb. Sometimes those pieces fall out, so be careful not to hold the flashlight too high. As you and your partner examine the insides of the flashlight, draw and label the parts in your science notebook."

The students take apart the flashlights and make rough drawings in their notebooks. Then Ms. Travis distributes strips of bell wire, one to each pair of students. "Let's see if you can use this wire, with one of the batteries and the bulb you have found, to get the bulb to light. Before you begin, let's look at these tools."

She holds up the wire strippers. "Where have you seen these before?" Some students recognize the wire strippers from tool kits they have at home. "Why are they important for our experiment?" Ms. Travis asks. Some students, who have prior knowledge about stripping wire, offer answers. Ms. Travis distributes the wire strippers and suggests that the students use them to bare the ends of their wires.

Ms. Travis's thinking: *Ms. Travis wants her students to learn by doing. However, she knows that the battery, bulb, and strip of wire will be cumbersome to manipulate, and she doesn't want the students to get so frustrated by lack of success that they lose interest. Thus she suggests that they strip the ends of their wire, giving them a better opportunity to solve the problem.*

The groups of students make several attempts before finding the ways that work. Most groups discover that the bulb will light if one end of the wire is wrapped around the bottom of the bulb and touching one end of the battery, while the other end of the wire is touching the other end of the battery. One group of students succeeds by stripping a portion of the center of the wire, wrapping that portion around the tiny bulb, and then touching either end of the battery with the free ends of the wire.

Students visit each other and try several ways to get the bulb to light. Ms. Travis asks them to draw the ways that work *and* the ways that do not work.

She then proposes that the students use *both* flashlight batteries and the wire to light the bulb. Manipulating the two batteries and one wire is tricky. But when they finally manage to get the bulb to light, they notice it is much brighter than it was with only one battery.

Ms. Travis asks the students to reassemble their flashlights, turn them on, and compare the light from the flashlight with the light that they have just created with the two batteries outside of the flashlight. The students notice that the brightness seems to be identical.

For homework, she asks them to write what they have done this morning in their science notebooks and to list some of the "rules" they have discovered for getting their bulb to light, first with one and then with two batteries.

The next morning, Ms. Travis empties the contents of the science electricity kit on the front table of the classroom. "Let's look at the materials we have to work with here. Can we identify some of them?"

The students recognize the bulbs as looking just like the bulbs in the flashlights. The wire, too, is identical to the wire they used the day before. Although the batteries are somewhat larger, the students have no trouble identifying them as batteries. But this kit also has battery holders and little bulb holders. Some students have seen these before, and others have not.

Ms. Travis says, "Each science group should take two bulbs, two bulb holders, a battery, a battery holder, and 60 centimeters of bell wire to start. You will also need a wire stripper. Our class's problem is this: How can we get both bulbs to light at the same time with as much brightness as possible? Start to explore your materials carefully. Notice how the battery holders and the bulb holders are constructed. Brainstorm with one another about where to attach your wires. Use the rules you developed from last night's homework. Then make a plan with all the members of your group. You will want to try out lots of ideas. Take your time!"

Ms. Travis's thinking: *The students are excited about handling the materials, but Ms. Travis knows that connecting the wires to the bulb holders and the battery holders is sometimes tedious. Planning their procedure beforehand may save the students unnecessary labor. Also the discussions among themselves should help them learn.*

The students gather their materials and develop their plans. Some have a sense of where to go; some ask Ms. Travis where to begin. She offers responses such as, "You may want to screw the bulbs into the bulb holders."

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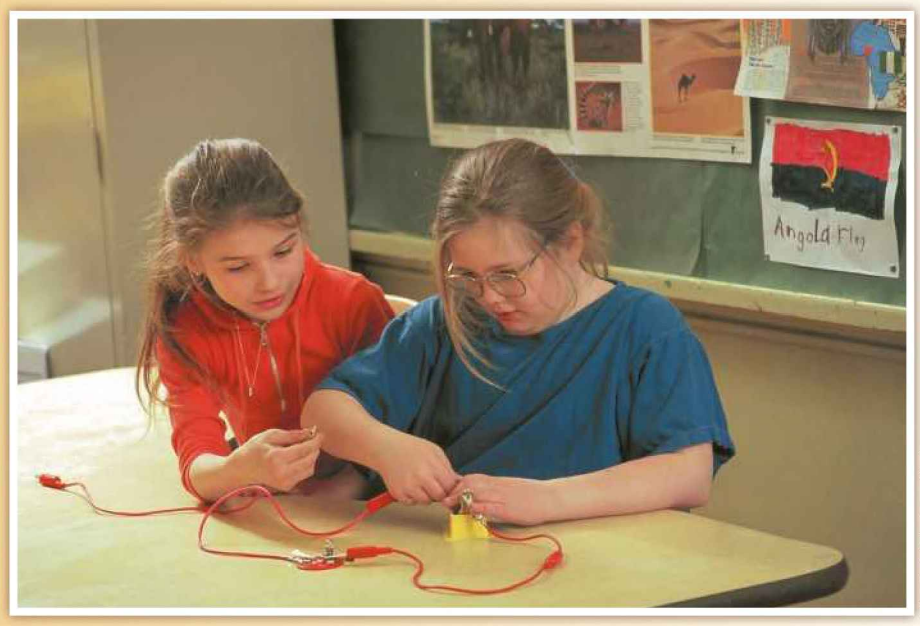

Ellen Senisi/The Image Works

PHOTO 9.1 These students are conducting their own investigation with batteries, bulbs, and wires. They are invested in solving their particular problem.

The students start stripping the ends of the wires. The groups are busy and engaged (Photo 9.1). Walking around the room, Ms. Travis notices varying levels of comfort with the materials. She points things out and makes further suggestions. She reminds one group, "You may have to cut that strip of wire. You may need more than one wire." To the class, she announces that they can have more wire if they need it.

Ms. Travis's thinking: *In walking around the room, Ms. Travis wants to see how the students are thinking. She is hoping that their experience the previous day will help them to construct their own electrical connections using these new materials.*

Most of the groups get the bulbs to light by using three pieces of wire and connecting the first wire from the battery holder to a bulb, the second wire from the first bulb to the second bulb, and the third wire from the second bulb back to the battery. They notice that the lights are very dim—much dimmer than when they used one bulb and one battery the day before.

After applauding their efforts, Ms. Travis begins to provide some labels for what they have created. "Can we label the pathways we have made with these batteries, bulbs, and wires?" she asks. "What do scientists call this type of path?" Some students shout out "circuit," and Ms. Travis writes the word on the chalkboard. Together, she and the students define a circuit as a complete pathway from one end of the battery, through the wire and the bulbs to the other end of the battery, and through the battery again.

This pathway, she tells them, is a continuous route for tiny charged particles called electrons. "These electrons carry the electric charge through the circuit. All these charged particles flowing along the wire is what is meant by an electric current." On the board, she draws a sketch of the circuit that the students have constructed (Figure 9.1).

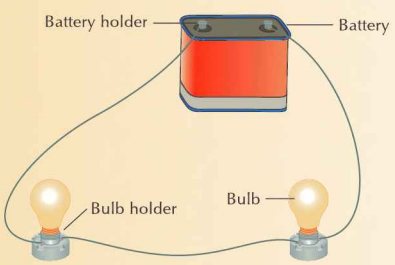

FIGURE 9.1 A series circuit with a battery in a battery holder, two bulbs in bulb holders, and three wires

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At this point she slips in a new question: "I hope this helps to explain why our bell wire is *coated.* Let's think about that as we work."

Ms. Travis's thinking: *At this point, Ms. Travis wants the students to associate the correct labels with the pathways they have created. She is not interested in brainstorming about the coating on the bell wire at this time; she just wants to plant the seed of this idea to see if it will germinate as they work with the wire.*

Now Ms. Travis challenges the students to create a circuit that could enable the bulbs to be brighter while both are still lit at the same time. She invites them to take more wire if needed. Once again, she circulates among the groups, directing and coaching, probing the students' thinking, and encouraging them when they get frustrated. "You may want to try one bulb at a time," she says to one struggling group. To another group she remarks, "Draw what you have done here. It really seems to work." With yet another group, she invites them to visit a group in the back of the room that has been more successful. All this time, students are trying to figure out how to light two bulbs at once with a single battery without making the bulbs so dim.

After a while, Ms. Travis asks one member of each group to come to the board and draw the circuits they have constructed. The solutions that work all involve using four wires and connecting each bulb to the battery independently of the other (Figure 9.2). The difference in brightness is very noticeable. The two bulbs connected independently of each other are much brighter than the two bulbs that shared the same circuit.

"It is time to label the two types of circuits you have made," Ms. Travis tells the class. "In this one"—she points to the drawing she made of their first circuit (resembling Figure 9.1)—"the electric charges travel in a single path, through the battery, the wires, and both bulbs. This is called a *series circuit.* In the second type of circuit that you made"—now she points to their own drawings (resembling Figure 9.2)—"each bulb is connected in its own separate pathway. This is called a *parallel circuit.* Now, let's take some more batteries, bulbs, and wires and set up both of these types at the same time."

The students set up a series and a parallel circuit, with one battery and two bulbs in each. Ms. Travis asks them to find different ways of extinguishing one or both of the bulbs. She then asks the students to write about their findings in their notebooks.

After some exploration, the students learn that, in the series circuit, any break in the pathway causes both bulbs to go out. In the parallel circuit, though, each bulb is affected independently, and for both bulbs to go out there must be a break in each of the separate pathways. Further, in the series circuit, the children notice that when they unscrew one bulb, the other one goes out. In the parallel circuit, when they unscrew one bulb, the other bulb stays on.

Before the morning is over, Ms. Travis asks the students in each group to come up with other questions that they want to investigate. "What are you most dying to find out? List the questions that your experiments with batteries, bulbs, and wires can help you figure out. Make sure that you also list the materials you will need."

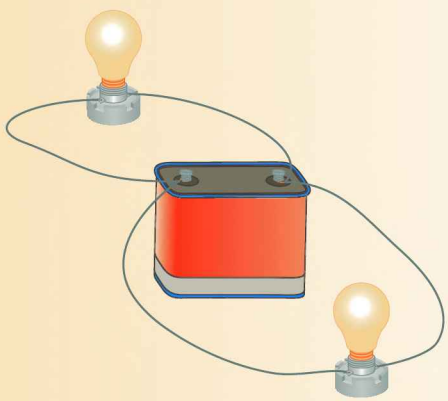

FIGURE 9.2 A parallel circuit with a battery, two bulbs, and four wires Because the bulbs are connected to the battery independently of one another, they will shine brighter than the bulbs in Figure 9.1.

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Here are some of the students' questions:

- Are the bulbs always brighter in a parallel circuit?
- What happens with two batteries in a series circuit? In a parallel circuit?
- What happens to the brightness in a series circuit that has three bulbs?
- What is a light bulb made of?
- What happens when we combine circuits with other groups?

Ms. Travis writes each question and the name of the child posing it on poster paper in the front of the classroom. The children will be exploring their own questions for many days.

9-3 Applying What They Learned

SCIENCE STORY

The Next Day: Lighting a Shoebox House

The following day, Ms. Travis brings in a large shoebox that is set up like a room in a little dollhouse. It has cardboard chairs and a little sofa. On one inside wall is a picture of a fireplace. Through a hole in the top of the box, a miniature bulb (like the flashlight bulbs the students have been using) hangs as a ceiling light. On the outside of the box, the bulb holder is connected to two long wires attached to a battery. The light works! Unlike a normal household light, however, this light has no switch, and the students are given time to think about what a switch might look like.

The children love the shoebox room. Ms. Travis now brings out several switches for their circuits, and she invites each group to experiment with circuits and switches. (You may remember that switches were included in the kit of materials that all the fourth-grade teachers in this district received.) How, Ms. Travis asks the students, could they make her shoebox room brighter? They all suggest another bulb, but the question of how to connect the other bulb becomes a point of discussion.

Ms. Travis then demonstrates the effects of lighting the room with two bulbs in a parallel circuit versus lighting it with the same bulbs in a series circuit (Figure 9.3). The students immediately notice that the parallel circuit makes the room brighter, just as their two bulbs were brighter in the parallel circuit they made the day before.

Examining Light Bulbs

Ms. Travis now uses the discussion of bulbs as an opportunity to introduce the students to full-size incandescent light bulbs and to compact fluorescent bulbs. They are more familiar with incandescent bulbs; however, Miranda's family has replaced all their incandescent bulbs with the compact fluorescent type. "Why did your family want to do this?" asks Ms. Travis. Miranda replies that the new bulbs use less electricity to make light.

Ms. Travis asks the students to get the networked laptops from the classroom computer cart. Challenging them to explore the Internet to learn how light bulbs work, she divides the class in half. Working in groups, half of the class explores how an incandescent bulb works. The students find a diagram of an incandescent bulb and discover that when electricity passes through the tungsten filament of the bulb, the filament gets very hot and glows, producing the light we see. Ms. Travis suggests that they look closely

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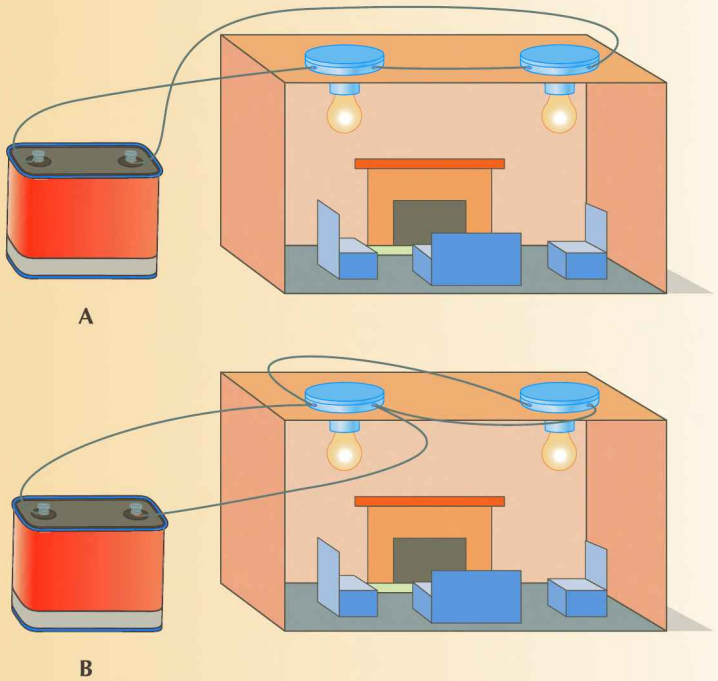

FIGURE 9.3 A shoebox room lighted with two bulbs (A) in series and (B) in parallel. In which setup are the bulbs brighter?

at the little bulbs with which they were working, and the students see that these bulbs have filaments, too. The students realize that these bulbs also work by changing electrical energy to heat energy.

The other half of the class, exploring the structure of the compact fluorescent bulb (CFL), discovers that CFLs work very differently from incandescent bulbs. These bulbs are glass tubes holding a gas made of the elements argon and mercury; the tubes have an interior white coating made of metallic compounds called phosphors. The gas gets excited by electricity and produces ultraviolet (UV) light, which is invisible. When this UV light hits the phosphor coating, it becomes visible light. The CFL has a coiled glass tube and a base that allows it to screw into standard lighting sockets.

Ms. Travis asks the reporters in each group to supply one piece of information they have discovered about each type of bulb. She then asks the class to access information about the CFLs. Ms. Travis poses the question, "Are fluorescent bulbs really more efficient than normal light bulbs?" As a class, the students explore this question together. Because fluorescent bulbs do not use heat energy to make light, the class discovers, these bulbs are more energy efficient than incandescent bulbs. In fact, each compact fluorescent light bulb uses 75 percent less energy and lasts ten times longer than an incandescent bulb! In a standard bulb, a lot of electricity is actually "lost" to heat energy. (You know how hot a standard bulb can feel after it is in use for a while.) The class concludes that we should say "Bye-bye" to regular light bulbs and that stores should sell only compact fluorescent bulbs. In fact, countries around the world are phasing out incandescent light bulbs, and most consumers are now only able to purchase CFLs for their home lighting needs.

Continuing Investigations

As the class's electricity investigations continue, Ms. Travis offers a list of questions for the students to answer at home:

- Is your home wired with fuses or with circuit breakers?
- Can you ask a parent or guardian to show you the fuses or circuit breakers?
- What types of things in your home work on electricity?

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- Do you have an idea about which appliances in your house may be connected in a series circuit and which ones in a parallel circuit? How could you find out?
- Do you use compact fluorescent bulbs in your house? Which rooms?
- Why is it important to conserve electricity?
- How is electricity related to greenhouse gases?

In addition to answering these questions at home, the students pursue many interesting activities in the classroom during the following days. Although the groups do not all do the same things at the same times, each group reports its discoveries to the class at large. For example, one group discovers that the more parallel circuits they place on a battery, the faster the battery will burn out. Another group uses a series circuit to make a tester, and they test which materials conduct electricity (Figure 9.4). Two groups create a series circuit around part of the room. It has four batteries and eight bulbs, and the students demonstrate how all eight bulbs go out when a single bulb is unscrewed. Ms. Travis also engages the students in building things with their circuits. Some students make a model flashlight; others build a blinking lighthouse and a quiz board that has secret circuits. Ms. Travis also allows a group of interested students to work on a class statement that provides five good arguments for using compact fluorescent bulbs to light your home or apartment.

The Teaching Ideas behind These Stories

- Notice how Ms. Stone gives vocabulary information at the beginning of the lesson, while Ms. Travis waits until the students have developed some understanding before providing new language. Although Ms. Stone is well meaning and hard working, research in science education reveals that students make better connections to the science vocabulary when it emerges from the context of their activity.
- Ms. Stone engages students in the exploration of electrical circuits on *her* terms. She controls the activities, the time students spend on each step, and the outcomes they should achieve. Ms. Travis controls much of the experimental design and the initial problem posing, but then gives the students control over procedures and findings.
- Ms. Stone is concerned that everyone "get" all the science ideas from her at the same time. Ms. Travis is certain that all the science ideas will emerge from the students, pieces at a time. She relies on the reports from the student groups to address ideas that do not emerge from the initial activities.
- Ms. Stone's procedures are lockstep and rigid. There is no room for students' own ideas about how to explore. Ms. Travis, in contrast, allows a diversity of procedures. Since science is a human activity, differences in specific procedures are common and important for learning.
- Ms. Stone does not provide personal connections or a personal context for the electricity unit. Ms. Travis provides such contexts by engaging the students with flashlights, a mock dollhouse room, light bulbs they have seen at home, and questions about their homes' wiring.

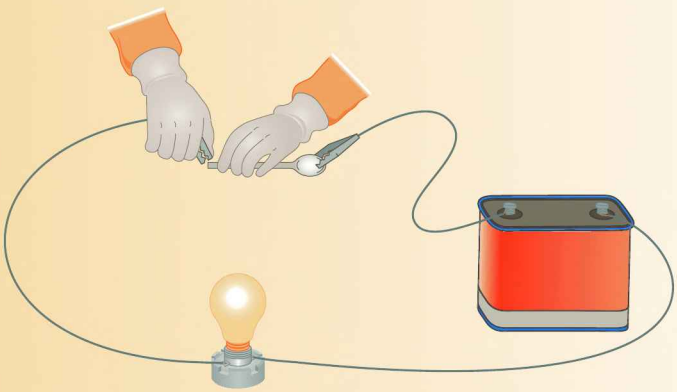

FIGURE 9.4 A simple electrical tester

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- Ms. Travis's students are employing several science and engineering practices while exploring the intricacies of electricity.
- Ms. Travis's students are likely to learn better and more deeply because they are conducting their own investigations and becoming invested in answering their own questions. They are doing more than just following directions and repeating the teacher's language.

The Science Ideas behind These Stories

- **Electricity** is a form of energy. In some respects scientists are still unsure of exactly what electricity is, but the word *electricity* is used to describe a flow of electrons. This energy was stored in the batteries the students used.
- **Electrons** are negatively charged particles that are found in the atoms of all elements. Each tiny electron is thought to be a particle of negative electricity.
- An **electric current** is a flow or motion of electrons. Electric currents in wires are caused by electrons moving along the wire.
- An **electric circuit** is a pathway for a current. A circuit requires some source of electrical power, such as a battery or generator; a pathway for the electrons, such as copper wire; and some appliance that uses electricity, like a light bulb or a bell.
- In a simple electric circuit using a light bulb and a battery, the electrons flow from the negative (flat) end of the battery through the wire to the bottom of the bulb (or the side of a bulb holder), through the filament inside the bulb and out the bottom of the bulb (or the other side of the bulb holder), through the other piece of wire to the positive (bumpy) end of the battery. The current then passes through the interior of the battery to complete the circuit. There is a continuous flow of energy through these devices unless some part of the circuit is stopped or broken—for instance, if a bulb burns out, a wire gets loose, or a battery is used up.
- In a **series circuit**—the type of simple circuit just described—the electric current has only a single pathway through the circuit. This means that the current passing through each electrical device is the same. Each time an electrical device, like a bulb, is added to the series circuit, the total amount of electrical force must be shared among a greater number of devices. That is why each bulb becomes dimmer when a new bulb is added.
- In contrast, in a **parallel circuit** each device has a separate pathway—its own separate branch of the circuit. Thus, if one bulb goes out, the other bulbs or devices in a parallel circuit are unaffected.
- Each device in a circuit offers a certain amount of *resistance* to the current. In a series circuit, two bulbs present twice the resistance of one bulb. Since the current equals the force divided by the resistance, each bulb gets only half as much current. In a parallel circuit, on the other hand, there is only one bulb per path; therefore, there is less resistance on each path, the current supplied to each bulb is greater, and the bulbs glow more brightly. This also means that the battery will burn out twice as fast, because it is supplying twice as much current as in the series circuit. See Chapter 10 for more information about electrical energy.

Connections to the Next Generation Science Standards

- **NGSS DCIs:**
  - **4-PS3-2 and 4-PS3-3: Definitions of Energy:** Energy can be moved from place to place by moving objects or through sound, light, or electric currents.
  - **4-PS3-2 and 4-PS3-4: Conservation of Energy and Energy Transfer:** Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light.

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- **NGSS SEPs:** Ms. Travis's students are *asking questions, defining problems, planning and carrying out investigations, constructing explanations and designing solutions*, and *developing and using models*.
- **NGSS CCs:** Students are engaged in the crosscutting concept of *cause and effect* as they test their circuits and *energy and matter*, showing that electrical energy can be transferred in various ways and between objects, in this case, starting with stored energy. They also see how science affects everyday life and that engineers improve existing technologies and develop new ones.

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- Explore a small flashlight bulb to see how it lights.
- Why would a house be wired in parallel and not in series circuits?
- In the experiments described in our science stories, why is it important to use bell wire, which is copper wire coated with a plastic sheath?

9-4 Thinking about Teaching and Learning: Science PCK

electricity
A form of energy produced by a flow of electrons.

electron
A negatively charged particle found in the atoms of all elements. Electrons revolve around the nucleus of the atom in different orbitals or "shells"; each shell represents a distinct energy level. Each electron is thought to be a particle of negative electricity.

electric current
A flow or motion of electrons. Electric currents in wires are caused by electrons moving along the wire.

electric circuit
A pathway for an electric current. A circuit requires some source of electrical power, such as a battery or generator, and a material through which electrons can travel, such as copper wire. In elementary school science, circuits usually include some simple appliance that uses electricity, like a light bulb or a bell.

Let's think further about the two teachers whose classrooms we have visited so far in this chapter. Ms. Travis holds out the expectation that her students are knowers, that they have their own ideas, and that they are capable of constructing and carrying out investigations on their own. This is Ms. Travis's belief system, and it influences her teaching practice. Her teaching is a good example of the principles that this book advocates. These principles can be labeled **science pedagogical content knowledge** or science PCK. This refers to the methods and strategies that specifically help people learn science. The model espoused by Ms. Stone may be thought of as a "transmission" model of science teaching, where Ms. Stone gives the students the content and the procedure for learning about electricity. Ms. Travis's model of science PCK may be thought of as "teacher as mediator." She is a mediator of science content where student predictions, experimentation, and explanation dominate classroom discourse.

She expands the science kit both in a literal sense, by letting her students use more materials and explore a wider range of activities than the school-supplied science box allowed, and in a metaphorical sense, by releasing herself and her students from the intellectual confinement of prepackaged instructions. She also expands the topic by allowing her students to explore ideas that relate to their own interests in electricity and environmental issues.

But what about Ms. Stone? Clearly, Ms. Stone works hard, has respect for her students, and cares deeply about their instruction. She is, however, unwilling to trust that her students can come up on their own with the activities that are neatly laid out, step by step, in the student workbooks in the fourth-grade electricity box. In Ms. Stone's personal model of teaching, she is the authority in the classroom. She believes that this is what the children require. She believes that they look to her for the right answers and that she is not doing her job unless she provides these answers.

This attitude is not uncommon, and it is not at all ill-intentioned. Well-meaning teachers all over the country believe that students learn only if the teacher tells them what and how to learn. You may be wondering, "Well, what

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series circuit
An electric circuit in which the current has only a single pathway through the entire circuit.

parallel circuit
An electric circuit in which each device has a separate pathway, its own separate branch of the circuit.

science pedagogical content knowledge (PCK)
Refers to science content knowledge that is transformed by the teacher into a format that makes it understandable to students.

is teaching if we don't tell students what and how to learn? What is left for us to do?" Think back to our earlier discussions of the teacher as mediator, and consider whether Ms. Travis is really doing *less* than Ms. Stone. And consider all the other science stories in this book that have shown teachers working very hard with their students. I think you'll find that the teacher who guides and mediates learning is doing lots of planning and active listening in ways that are not required of a teacher who merely "delivers" instruction. Also, even though Ms. Travis does not behave like an absolute science authority in the classroom, she is actually taking on a great deal of authority because she assumes the responsibility of constructing the science experiences with her students. It requires a lot of self-reliance—as well as thoughtful consideration—to take a package or kit of materials, discard the prescribed instructions, and ask yourself, "How can I use the materials in this science box to create a meaningful learning experience for *my* students?"

9-4a The Learning Cycle Revisited

In Chapter 1 we discussed a useful tool for your own science pedagogical content knowledge. This is the learning cycle or the five-phase model of Engage, Explore, Explain, Elaborate, and Evaluate. In each of these phases of the learning cycle, students are active and constructing meaning from experience. Notice how these five phases are implemented by Ms. Travis in her fourth-grade electricity lessons.

She *engages* them by asking them to purchase a pound of electricity. The conversation then yields the difference between matter and energy. The *exploration* phase begins as she distributes materials to the science group and asks them specifically to "explore some flashlights." She suggests that they work in pairs and asks them to draw and label the parts of the flashlight. They continue their explorations with batteries, bulbs, wires, and wire strippers and making a light bulb light.

During the *explanation* phase, she actually provides labels for their electrical pathways and the students are introduced to the terms *circuit*, *series circuit*, *parallel circuit*, and *switch*. They also learn how different light bulbs work and which ones are better for the environment.

The next day, students begin to *elaborate* on their previous explorations by applying what they have learned to making a shoebox room with lights. Their *evaluation* phase is implemented when Ms. Travis requires the students to apply what they know about circuits to the process of design by creating different types of circuits such as a tester for materials that conduct electricity, making a model flashlight, or building a quiz board that has secret circuits.

Teachers need to explore pedagogical knowledge and acquire a depth of understanding of the science content. This is a beginning to developing one's own science PCK. The contrast in this chapter's lessons represents the intersections of knowledge and beliefs as they impact classroom practice and remind us that "we teach who we are." Learning what works best on behalf of your own and your students' science learning is an important step to creating your personally effective model of science teaching.

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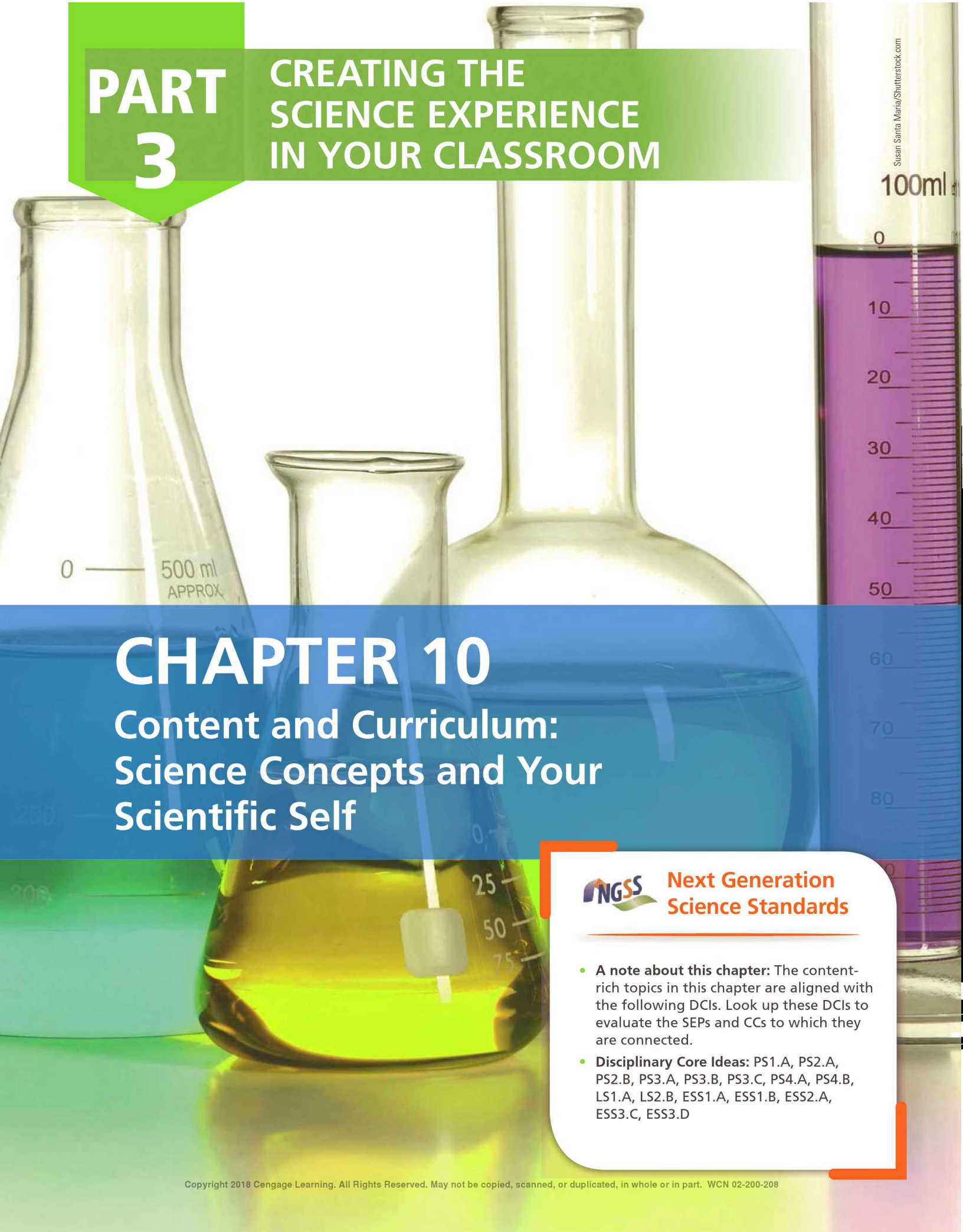
PART 3 CREATING THE SCIENCE EXPERIENCE IN YOUR CLASSROOM



CHAPTER 10

Content and Curriculum: Science Concepts and Your Scientific Self

Next Generation Science Standards

- **A note about this chapter:** The content-rich topics in this chapter are aligned with the following DCIs. Look up these DCIs to evaluate the SEPs and CCs to which they are connected.
- **Disciplinary Core Ideas:** PS1.A, PS2.A, PS2.B, PS3.A, PS3.B, PS3.C, PS4.A, PS4.B, LS1.A, LS2.B, ESS1.A, ESS1.B, ESS2.A, ESS3.C, ESS3.D

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 10-1 Examine how to make the scientific concepts that are new to you "your own."
- 10-2 Describe the range of science topics addressed by life science, physical science, and earth and space science.
- 10-3 Discuss what makes "system thinking" different from just knowing the parts of a system.
- 10-4 Examine the major components of the solar system and the laws of motion that govern it.
- 10-5 Discuss four of the major human body systems that help matter and energy flow through the organism and sustain life.
- 10-6 Examine six types of simple machines and how they work.
- 10-7 Analyze the ways the earth is like a giant system.
- 10-8 Discuss the law of conservation of matter and energy.
- 10-9 Describe the differences among radiation, conduction, and convection of heat energy.
- 10-10 Discuss where electrons come from and how they function in current and static electricity.
- 10-11 Examine the sources of light energy and how light energy travels.
- 10-12 Explain why sound energy requires a medium through which to travel.
- 10-13 Analyze the complex role of magnetism in our world; explain why it is a force.
- 10-14 Discuss the relationship between the NGSS and the science curriculum.
- 10-15 Examine the implications of the STEM movement.
- 10-16 Select a mini-science unit, develop some activities in which to engage the students, and identify the relevant grade level.

Reflection To Think About:

- What core science concepts are the basics for an understanding of how the natural world works?
- How do you personalize science content and make it your own?
- When you think of a natural system, what comes to mind?

As a child, I was always highly curious about things, especially things related to nature, but there was very little available at my reading level that presented answers to my questions in ways that I could readily understand. Many teachers I meet used to feel the same way. You may have felt this way, too. Today, we are fortunate to have access to websites, blogs, Twitter, and wikis, all of which can be useful in explaining scientific principles. In fact, knowing how to navigate the Web to find just the right explanations is a useful skill lest we be overwhelmed by too much information. The National Science Teachers Association has relevant links for science content for elementary and middle school teachers. Called "Science Objects," these links are two-hour, online, interactive, inquiry-based modules that help teachers better understand the science content they teach.

As you have noticed in the science stories throughout this book, effective teachers guide students as they make sense of new ideas. Teachers listen and reflect back to the students their understandings of the ideas; these conversations help to further the students' thinking about a concept. A teacher's ability to do this is often related to his or her own level of comfort with the scientific material and understanding of the content.

As a teacher, then, you'll want to continue developing your own understanding of science concepts. In this chapter, I hope to give you a guide to some of the science content your students will be exploring. The chapter cannot discuss all of the topics you will delve into, but the ideas and understandings described here will help you frame many of your learning goals for your students.

After discussing some of the major science topics that elementary and middle school students investigate, this chapter will go on to explore how these topics are organized into a curriculum that responds

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to local, state, or national standards or frameworks. Wherever you teach, you will probably be given a textbook or a set of materials that represents the curriculum you are supposed to "cover." As you've seen throughout this book's *Science Stories*, however, our role as teachers is not just to "cover" a curriculum but to help students *uncover* the ideas and meanings that emerge through their own experiences. This chapter will help you understand how to approach a science curriculum so that this learning can truly take place.

10-1 Making New Concepts Your Own

evidence
In science, evidence refers to the total amount of information that is used to demonstrate or determine the truth of an assertion, such as a fact or a theory.

The major governing science concepts from the Next Generation Science Standards (NGSS) are often called "disciplinary core ideas (DCIs) " or "science ideas" or "big ideas." The ones presented in this chapter have emerged from repeated experimentation and investigation, and they form part of scientists' "taken-for-granted" way of seeing things (Driver et al., 1994). These DCIs are commonly the basis for a lot of elementary and middle school science curriculum. Remember that science ideas are arrived at after analyzing a great deal of **evidence**, and arguing from evidence is one of the eight science and engineering practices described in the NGSS. This is *how* science works, and these science ideas are the result of lots of experimentation. In a similar way, we encourage you and your students to engage in activities that allow them to reach conclusions about the natural world.

Hence, these concepts were arrived at by lots of intellectual struggle among scientists who have engaged with each other and individually in making sense of their observations and experience. These ideas were created through the same sort of knowledge construction and conversation that you have seen in classrooms.

Understanding this, it is important to recognize that just by reading the following science ideas or concepts you will not make them your own. You need to interrogate these ideas in the ways you know your own students will have to do. To construct your own meaning for the science concepts in this chapter, access your own capacity for metacognition and ask yourself the following questions:

- Have I had any experience with this science concept?
- Does it make sense to me?
- How can I find out more about this topic?
- How does this concept fit in with what I already believe about nature?
- How could I express this idea differently?

Having this conversation with yourself will help you to develop your scientific self and make these ideas your own. As you have noticed throughout *Science Stories*, it is even more helpful to discuss science concepts with others who may have different interpretations and prior experiences. Having such conversations helps you to clarify your own understandings.

10-2 Organizing the Science Curriculum

As noted in earlier chapters, students' scientific explorations will address a wide variety of topics, from classroom animals to electric circuits to the solar system. A traditional way of organizing this multitude of topics is to divide them into the three areas of life science, physical science, and earth and space

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science. Often environmental science, including the types of "green science" we have discussed in this book, falls under the life science or earth science classification, depending on the topic. When we talk about disruptions to ecosystems, for example, it is a topic for life science.

- In *life science*, students and teachers explore characteristics of living things and their interactions with the nonliving environment. They explore ecosystems, heredity, and evolution.
- In *physical science*, students and teachers look at properties of objects and materials, forms of energy, and the motion of objects.
- In *earth and space science*, students and teachers investigate earth's materials and systems, earth's place in the universe and the earth and human activity.

We can also examine science topics across disciplinary boundaries by organizing them into *Systems* and *Interactions and Patterns of Change*. These categories will help you to look at science content differently, furthering your understanding of how the areas of elementary and middle school science relate to one another. This approach to science content is also consistent with the idea of crosscutting concepts described by the NGSS.

Figure 10.1 illustrates the way a number of typical science topics fit into the two conceptual categories. For reference, the figure also identifies the topics according to the three traditional science areas. Whatever way the material may be organized in your own school's curriculum, you can make it come alive by challenging yourself—and your students—to see what apparently different topics have in common.

	Systems	Interactions and Patterns of Change
Life science	■ Human body systems ■ Plants and animals ■ Ecosystems	■ Life cycles ■ Tropisms ■ Food chains
Physical science	■ Sinking and floating ■ Simple machines	■ Chemical and physical change ■ Heat energy ■ Electricity and magnetism ■ Light energy and color ■ Sound energy
Earth and space science	■ Solar system; Planetary motions ■ Earth as a super system ■ Moon phases	■ Weather and seasonal change ■ Earth motions ■ Rocks, soil, erosion ■ Earthquakes and volcanoes **Environmental science:** ■ Conservation and recycling ■ Air and water pollution

FIGURE 10.1 Basic science topics
Here some typical topics of elementary and middle school science are organized in two ways: by conceptual category and by the traditional areas of life science, physical science, and earth and space science. There will often be overlap between Systems and Interactions and Patterns of Change.

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10-3 Systems

Understanding how systems operate requires that you identify how the parts of a system interrelate and combine to perform specific functions. You also need to recognize the commonalities that exist among all systems.

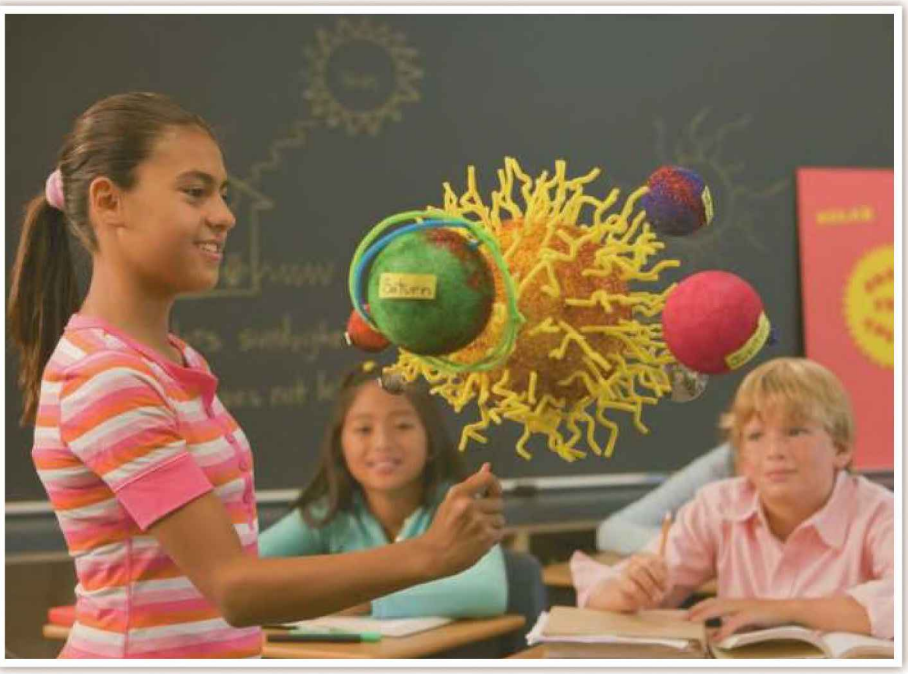
As you read and think about systems, the useful questions you can ask yourself include these:

- Is this system open or closed, or both?
- Is it a naturally occurring system?
- Do human beings impact this system? How?
- How do the parts of the system contribute to the functioning of the whole?

In the school science curriculum, students are often asked to observe and describe interactions among components of simple systems. As examples, I have selected four topics commonly taught in elementary and middle school that relate to systems: the solar system, the systems of the human body, simple machines as systems, and the earth as a system. In the NGSS, the crosscutting concept of Systems and System Models states that specifying a system's boundaries and making explicit a model of that system provides tools for understanding and testing ideas that are applicable throughout science and engineering.

10-4 The Solar System

The solar system is made up of a group of objects, sometimes called heavenly or celestial bodies, that move around the sun (Photo 10.1). These celestial bodies are also called *satellites*. Satellites can move around the sun or around other celestial bodies. Hence, the moon is a satellite of the earth. The earth itself is a satellite of the sun; or we could say that the earth–moon system is a satellite of the sun. When one heavenly body moves around another, we call that movement *revolution*.



Ariel Skelley/Jupiter Images

PHOTO 10.1 Students explore a model of planetary motion as they try to make meaning.

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10-4a The Sun and the Planets

The sun is a *star,* one of billions of stars in the universe. Unlike the earth, the sun is not a solid body; rather, it is a huge ball of extremely hot gases. It is much larger than the earth. In fact, the diameter of the sun at its equator is 109 times greater than the diameter of the earth. As we saw in an earlier chapter, if the sun were a hollow ball, we could fit over a million earths inside it. Nevertheless, compared to other stars in the universe, the sun is not a particularly large star. It appears larger to us than other stars because it is so much closer to earth. We often refer to it as *our star.*

There are eight planets that travel around the sun. Along with the sun, these planets are considered the major members of the solar system. Planets are much smaller than the sun and do not make their own light. They shine in the night sky by *reflecting* the light of the sun.

The eight planets travel around the sun in specific paths called *orbits.* Since these orbits are slightly elliptical, all eight planets move closer to and farther from the sun at different points in their orbits. As you saw in the Chapter 8, the average distances of the planets from the sun place them in the following order: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

Most planets *rotate*—that is, spin like a top—as they travel around the sun. Hence, we say that they are rotating as they are revolving. They rotate around an imaginary axis that runs though the north and south poles of each planet. The time needed for each planet to make one complete rotation is called the planets' *day,* and the time needed for the planet to make one complete revolution around the sun is called the planet's *year.* All the planets revolve in a counterclockwise direction around the sun; however, their periods of rotation and revolution differ quite a bit from each other. Obviously, the farthest planets have the longest periods of revolution, while the closest planets revolve in the shortest amount of time. Mercury's eighty-eight days of revolution make its year much shorter than the 365-day earth year.

Most of the planets have satellites of their own. Like earth's satellite, these are called moons. As of this writing, astronomers have discovered more than 160 moons in the solar system.

10-4a Smaller Objects in the Solar System

Other celestial objects in the solar system include *asteroids,* which are also called planetoids. There are many theories about how these chunks of rocklike materials formed, but they travel together in what is referred to as the *belt of asteroids.* This belt contains more than 25,000 asteroids orbiting the sun between Mars and Jupiter.

The asteroids are much smaller than planets. They reflect light like planets do, and they differ in size and brightness. They are really like little planets, which is why they are also called planetoids.

Other rocks, called *meteors,* are found in the space through which the earth travels as it orbits the sun. When meteors encounter the earth's atmosphere, the force of friction between the meteor and the atmosphere causes the meteor to heat up and begin to burn. As they burn up, they look like stars shooting across the sky, and for that reason they are often called "shooting stars," a term that confuses them with real stars. Meteors that fall to earth without burning up are called *meteorites.* Sometimes meteorites form craters when they crash into the ground.

Comets are celestial bodies that revolve around the sun in long, oval-shaped orbits that sometimes cut across the orbits of the planets. Comets are made up of small rocks and dust mixed with frozen gases. As a comet nears

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the sun in its orbit, it appears to form a "tail," which is really the changing of the frozen gases into vapor. A comet's tail may be millions of miles long; but as its orbit takes it away from the sun's proximity, the comet "loses" its tail. Some comets make regular appearances. For instance, Halley's Comet orbits the sun every 76 years; it was last visible from the earth in 1986. Other comets are seen once and never return, appearing to waste away. No one is quite sure how comets form.

Beyond Neptune, the eighth planet from the sun, are more than one thousand other orbiting bodies, much larger than asteroids but much smaller than planets. This region of the solar system is called the Kuiper belt, and the orbiting objects here are more similar to frozen gases than to the rocklike asteroids. This is where Pluto is found. As we saw in Chapter 8, Pluto is no longer considered a planet but rather a dwarf planet. In 2008, the International Astronomical Union approved a new term to designate Pluto, its counterpart Eris, and other dwarf planets beyond Neptune: plutoids, a name that means Pluto-like bodies.

10-4c Gravity and Inertia: Governing Principles of the Solar System

Think about all these planets, moons, asteroids, plutoids, Kuiper belt objects (KBOs), and other celestial objects moving together in much the same way over billions of years. What makes these components into a system? Here we have a traditional earth science unit, but to understand it we need to call on two important principles of physical science: (1) the law of gravitation and (2) inertia.

1. *The Law of Gravitation.* You may ask yourself: What causes the paths of planets to bend into orbits around the sun?

   The scientist Isaac Newton (1642–1727) helped to explain the underlying reasons why the planets, their moons, and other objects in the solar system move in the way they do. The most important and significant understanding is called Newton's law of **gravitation**, which states that every body in the universe attracts or pulls on every other body with a gravitational force that increases when the masses of the objects increase and decreases as the objects move farther away from each other.

   gravitation
   The attraction of any two objects that have mass. According to the law of gravitation, every body in the universe attracts every other body with a force that increases when the masses of the objects increase and decreases as the objects move farther away from each other.

   In the solar system, each of the objects exerts a gravitational pull on each of the other objects. Because the sun is enormous in comparison to the planets and other objects, it has a much greater pull of gravity than any other body in the solar systems system. The continual, mutual gravitational attraction between the sun and the planets keeps the planets revolving in their orbits around the sun. The sun tends to pull the planets toward itself, but the distance of the planets from the sun and their mutual gravitational attraction for each other serve to keep them in defined paths.

2. *Inertia.* A body in motion tends to continue in the same motion at the same speed unless it is acted upon by an outside force. Similarly, an object at rest tends to stay at rest unless it is acted upon by an outside force that gets it moving. These ideas were also constructed by Isaac Newton after repeated experiments and investigations. They are known as Newton's first law of motion.

   The tendency of a body to continue with the same motion at the same speed or to remain at rest is called **inertia**. This principle is responsible for the fact that the planets, once they are moving in a certain path, remain in that motion unless some outside force changes it.

   inertia
   The tendency of a body to continue with the same motion at the same speed or to remain at rest.

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Thinking About Systems

The Interconnection of Parts

Frequently, students are immersed in learning about the parts of a system without studying the larger picture: how do the parts connect? In the case of the solar system, each planet and each planetary system (those with one or more moons) affects and is affected by the gravitational attraction between objects in the universe. It is their cumulative *effect on each other* that maintains the entire solar system in its continual pattern of orbital motion.

The human body is another complex system—in fact, it is a system composed of a number of smaller systems. In a typical life science unit in elementary or middle school, students explore in depth the body's digestive, circulatory, respiratory, and nervous systems. Therefore, in the following section, I have chosen to expand on these four body systems. It is important to stress, however, that all these systems function together to maintain the lives of human beings. Hence, as we explore four of the major body systems, we will also be thinking about how interconnected they are.

You can see that the solar system is indeed a working *system,* like an enormous, complex mechanism with many diverse components. The sun is at the helm, so to speak. It drives the orbits of the smaller parts with its enormous gravitational pull, relying on inertia and gravitational attractions to maintain the smaller objects' constant motion in their paths so that nothing comes crashing into the sun.

10-5 Human Body Systems

In the science story "What Makes a Rabbit Real?" (in Chapter 6), you saw young children beginning to understand the most important aspect of living things: their ability to exchange materials with their environment, taking in what they need and getting rid of what they do not need. Our body systems help to perform these functions for us.

A *body system* is a group of organs that work together on a specific bodily activity. There are a number of large systems in the human body. Working all together, they produce this smoothly running machine called the human body.

One typical way of thinking about body systems is to divide them into ten different but connected systems:

1. The *skin system* that covers the body and includes our nails, hair, and skin. The skin is thought of as the largest organ in the body.
2. The *skeletal system* of bones that support us.
3. The *muscular system* that makes it possible for the body and its parts to move; this system includes our muscles, ligaments, and tendons.
4. The *digestive system,* including the mouth, stomach, intestines, and liver, which breaks down foods so that all parts of the body may use the nutrients they need to produce energy and grow.
5. The *circulatory system* that uses our blood vessels and capillaries to transport nutrients and get rid of some wastes.
6. The *respiratory system* that allows us to breathe in and out by using the nose, windpipe, lungs, and diaphragm.
7. The *excretory system,* including the kidneys and bladder, that gets rid of the waste products formed in the body.

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8. The *reproductive system* that produces offspring and includes organs that affect sex characteristics.
9. The *endocrine system,* a system of glands that secrete chemical messengers, called hormones, which control and regulate the actions of the body.
10. The *nervous system,* including the brain, neurons (nerves), and the spinal cord.

All living body systems are made up of tissues that develop to perform specific functions, and these tissues are made of specialized cells designed to perform specific functions, not only in humans, but in all animals and plants. The following sections describe four body systems that students frequently examine in their school science units. As you read, think about interconnections among body systems. Notice how often, in describing one system, we make reference to another related system.

10-4a The Digestive System

digestive system
The body system that breaks down food into a form that can be absorbed and used by the body.

The body needs food in order to live and grow. The foods we eat contain materials that give the body energy and enable it to build and repair tissues and regulate other activities. The **digestive system** breaks food down into particles so tiny that blood can take nourishment to all parts of the body. The food undergoes a process of physical change as it goes from larger pieces to smaller pieces. It also undergoes a process of chemical change as it is transformed into soluble nutrients that can pass through the membranes of organs and blood vessels and into the body cells. We will explore other aspects of physical and chemical changes later in this chapter.

The digestive system's main part is a 30-foot (9-meter) tube from mouth to rectum called the *alimentary canal.* Muscles in this food tube force food along. This muscular action, called peristalsis, is strong enough to allow a person standing on his or her head to chew something and have it go "down" (really up) to the stomach.

In the mouth, food is physically changed when it is chewed by our teeth; it is also chemically changed by the chemicals in our saliva. The food then travels from the mouth to the stomach by way of the part of the food tube known as the *esophagus.* For two to three hours, food stays in the stomach, where digestive juices further change it.

After the stomach churns and liquefies the food, it passes through the very convoluted small intestine, which is 23 feet (7 meters) long. In the small intestine, digestive juices from the gallbladder, the small intestine itself, and the pancreas break down food particles. Many of these broken-down particles filter out through tiny, fingerlike structures on the inside of the small intestine called villi. Food that cannot be digested or used by the body passes from the small intestine into the large intestine as waste material. There, this undigested food forms feces and leaves the body through the anus. This process is referred to as elimination.

The parts of the digestive system all work together to ensure that food is broken down and absorbed and unwanted food is eliminated. For the system to be effective, it must complete all three of these main tasks. As we explore the circulatory system, you will see that digesting the food would be useless if our blood could not transport the digested nutrients to the body cells.

10-4a The Circulatory System

circulatory system
The system that maintains a continuous flow of blood around the body. The main parts of this system are the heart, arteries, veins, and capillaries.

The **circulatory system** is made up of the heart and blood vessels, which together maintain a continuous flow of blood around the body. The circulatory system has three main functions:

1. To carry digested nutrients to the cells in the body.

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2. To bring oxygen to the cells so it can be combined with the nutrients to release energy.
3. To take away soluble waste materials and carry them to organs that remove them from the body.

The heart pumps oxygen-rich blood from the lungs to all parts of the body through a network of tubes or blood vessels called *arteries* and smaller branches called *arterioles.* Blood returns to the heart through small vessels called *venules,* which lead in turn into larger vessels called *veins.* Notice that arteries carry blood away from the heart, while veins carry blood back to the heart.

A network of tiny blood vessels called *capillaries* links arterioles and venules. Capillaries reach all parts of the body, and they are the sites where the blood deposits oxygen and picks up carbon dioxide. This ongoing exchange between the blood and the body cells is regulated by the circulatory system.

The heart pumps the blood to every part of the body and back again in about thirty seconds. The blood, a liquid organ, has four main parts:

1. *Red blood cells* pick up oxygen from the lungs and carry it to the cells in the body. The cells use the oxygen to burn food, and the waste material is produced as carbon dioxide. Red blood cells pick up the carbon dioxide and carry it to the lungs, where it is given off.
2. *White blood cells* are much less numerous than red blood cells (ratio of 1 to 600) and their purpose is to destroy bacteria and other disease germs.
3. *Platelets* are tiny cells, even smaller than the red blood cells, and their function is to help the blood clot when the body is injured and bleeds. The clot prevents the blood from flowing out of the body.
4. *Plasma* is the liquid portion of the blood.

The heart is a strong muscle, about the size of your fist, located to the left of the middle of the chest. It contracts and relaxes, acting like a pump. When it contracts, it pushes blood into the arteries; when it relaxes, blood flows into it from the veins. The human heart has four chambers: two upper chambers, called the right atrium and left atrium, and two lower chambers, called the right ventricle and left ventricle. The two sides of the heart are completely separated by a wall called a septum; hence, blood in the two sides of the heart does not mix.

The atria receive blood from the veins and pump it down to the ventricles. (Valves on both sides of the heart prevent blood from flowing back into the atria.) The ventricles then pump blood into the arteries. The right ventricle pumps blood to the lungs via the pulmonary artery, and the left ventricle pumps blood to the other organs of the body via the artery named the aorta. The steps look something like this:

1. The blood is pumped out of the right ventricle to the lungs, where it picks up oxygen and deposits carbon dioxide. The reasons for this exchange will become apparent as you read about the respiratory system in the next section.
2. The oxygen-rich blood then leaves the lungs and goes to the left atrium, where it is pumped to the left ventricle and then to the entire rest of the body, depositing oxygen to the body cells.
3. The blood returns to the right atrium of the heart, filled with carbon dioxide from the body cells and needing oxygen. It then is pumped to the right ventricle and starts the cycle all over again.

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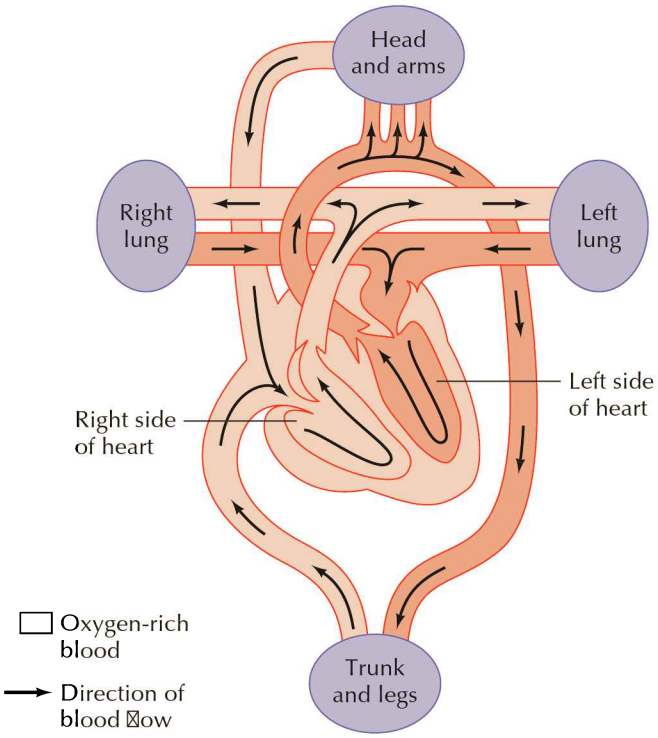

FIGURE 10.2 The circulatory system
The right side of the heart pumps blood to the lungs, where it picks up oxygen and gives up carbon dioxide. This oxygen-rich blood then goes to the left side of the heart, which pumps it to the rest of the body. The cells of the body use the oxygen and give off carbon dioxide, which the blood then carries back to the right side of the heart, where the cycle begins again.

The *circulation* of the blood from the heart to the lungs and back again, and from the heart to the entire rest of the body and back again, is what gives this system its name. Figure 10.2 shows a simplified, schematic diagram of the circulatory system.

10-5c The Respiratory System

respiratory system
The system that supplies the oxygen needed by body cells and carries off their carbon dioxide waste.

The **respiratory system** supplies the oxygen needed by body cells and carries off their carbon dioxide waste. Inhaled air passes via the trachea (windpipe), through two narrower tubes called bronchi, into the lungs. Each lung is made up of many fine, branching tubes called bronchioles, which end in tiny clustered chambers or air sacs called alveoli.

The alveoli look like tiny clusters of grapes, and each lung is one great mass of these air sacs. Gases in the air pass through the thin walls of the alveoli to and from a network of capillaries. Thus, the oxygen in the air enters the blood through these air sacs. The capillaries send the oxygen-rich blood to the left side of the heart, where it is then pumped to the rest of the body.

The cells in the body use the oxygen to combine with digested food, producing energy and giving off carbon dioxide. The red blood cells then pick up the carbon dioxide, and this blood is pumped back to the right side of the heart, where it travels to the lungs via the pulmonary artery. Now the carbon dioxide leaves the blood, diffusing through the thin walls of the capillaries and of the alveoli. The air containing the carbon dioxide is then forced out of the lungs, and the fresh air containing oxygen is forced into the lungs.

respiration
The metabolic process by which cells take in the oxygen they need and give back carbon dioxide as a waste product.

The term **respiration** refers to this exchange of gases. Think again about the students in Chapter 6 who discussed the exchange of materials in which living things are engaged. Respiration and digestion are two of the body processes that implement this exchange.

Respiration should not be confused with breathing. When we talk about *breathing*, we are referring to the mechanical process of getting oxygen-rich air

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into the lungs and getting carbon dioxide–rich air out of the body. *Respiration* refers to the metabolic process by which cells take in the oxygen they need and give back carbon dioxide as a waste product.

10-5d The Nervous System

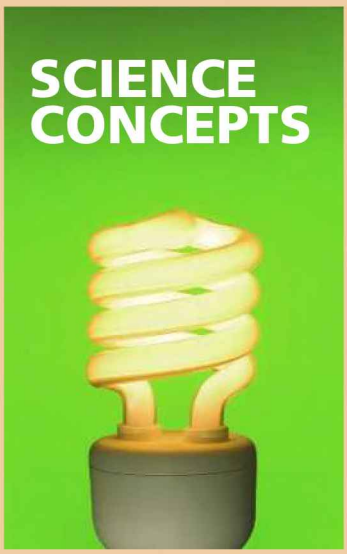
nervous system
The body's internal communications network, including the brain, spinal cord, and nerves.

The **nervous system** is the body's internal, electrochemical communications network. Its main parts are the brain, spinal cord, and nerves. The nervous system has many functions, including controlling the actions of the organs, muscles, and other tissues; controlling sensations such as smell, taste, sight, hearing, touch, pressure, heat, cold, and pain; and controlling thinking, learning, and memory.

The brain and spinal cord form the *central nervous system,* the body's chief controlling and coordinating mechanism. The brain is located in the skull, and the spinal cord lies along almost the entire length of the back. The spinal cord connects with the brain stem through a large hole in the base of the skull. The brain is the major organ of the nervous system and the control center for the body's voluntary and involuntary activities. It is also responsible for the complexities of thought, memory, emotion, and language. In adults, the brain weighs a mere 3 pounds (1.4 kilograms) but contains more than ten thousand million nerve cells.

The brain has three distinct regions: the brain stem, the cerebellum, and the cerebrum, each responsible for controlling different types of bodily functions. The *brain stem* controls vital bodily functions such as breathing and respiration, circulation, and digestion. The *cerebellum*'s main functions are the maintenance of posture and the coordination of body movements. The *cerebrum,* the largest region, consists of the right and left cerebral hemispheres, and it is the site of most conscious and intelligent activities.

How Do We Breathe?



A common alternative conception is that when we inhale, the lungs draw in air and the chest therefore expands. This is not true.

What actually happens is that air outside the body is forced into the lungs when the air pressure inside the body becomes lower than the air pressure outside. How can that occur?

When you begin to take a breath, a sheet of muscle in the bottom of your chest cavity, the *diaphragm*, contracts and moves downward. Simultaneously, your rib muscles contract and move upward and outward. These movements increase the size of your chest cavity, thus reducing the pressure of the air already in your lungs. (When you expand the space that a gas occupies, the pressure drops.) Air then rushes in from outside. When you exhale, the reverse occurs: The muscles in your diaphragm relax and your ribs move downward and inward, forcing air out of your lungs and out of your body.

The nose and nasal passages, the throat (pharynx), the windpipe (trachea), and the voice box (larynx) are all part of this system. They are passages through which the air passes. In the nasal passages, the air is warmed and moistened and tiny dirt particles are trapped. The back of the throat has a flap over the trachea called the epiglottis, which closes when food and water enter the throat, thus preventing the food and water from entering the windpipe.

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Thinking About Systems

Noticing Similarities and Differences

Some systems are *open*, meaning that materials enter them and leave them. Other systems tend to be *closed*, so they do not receive external material or discharge material. Still other systems are open and closed at different times.

The digestive and respiratory systems are obviously open systems. What about the circulatory and nervous systems—are they open or closed?

The circulatory system is closed in the sense that the blood vessels and organs are contained within the body. When we bleed, however, the system is open. More important, when we exchange gases through the respiratory system, the circulatory system receives and releases those gases. In that sense, too, it is open.

The nervous system may be thought of as open in that it responds to external as well as internal stimuli. It is also closed in the sense that nothing tangible enters or leaves it.

You can see how complex and interrelated the body systems are. Think about these further questions:

- Is the solar system an open or closed system?
- What do the sun, the alimentary canal, the diaphragm, the heart, and the brain have in common?
- In what ways is the circulatory system like a transportation system?
- What do you think is meant by the often-used term *brain dead*? How could a person be alive if his or her brain were dead?
- How would *you* define a system on the basis of what you have just read and thought about?

We use the word *system* to mean many different things. We talk about political systems, for example, or school systems or transportation systems. The scientific idea of a system implies detailed attention to inputs and outputs as well as to interactions among the system components. In the next section, as you explore simple machines—a traditional physical science unit—think about what connections might be drawn among these devices, the solar system, and the human body. What links and similarities do you see yourself? What ideas might your students explore? In what ways is the functioning of the human body like a system of machines?

Nerves spread out from the brain and spinal cord to every part of the body. There are three main types of nerve cells, or *neurons*:

1. *Sensory neurons* are the nerve cells that allow us to experience sensations. The cell bodies of these neurons are located in the brain and spinal cord, but they have long fibers that spread out to sense organs all over the body.
2. *Motor neurons* have to do with producing motion in the body. Their cell bodies are also located in the brain and spinal cord, and their fibers spread out to muscles, tissues, and organs of the body.
3. *Associative* or *central neurons*, located between the cell bodies of the sensory and motor neurons, transfer nerve impulses from the sensory neurons to the motor neurons. That is, the associative neurons act as go-betweens for receiving and sending messages in the nervous system.

The brain, the spinal cord, and the system of billions of long neurons control the operations of all other systems in the human body.

10-6 Simple Machines

Frequently, students learn about simple machines as discrete topics. Each type of machine discussed is not connected to other simple machines or to more complex machines. In this section, you'll read about several kinds of simple

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machines. As you read, consider how they relate to each other. Ask yourself questions like these:

- Where do I use this machine?
- How does it make work easier?
- Where does it appear as part of a more complicated device?
- What makes it a system?

Remember, reflecting on the concepts that you read, having conversations about them, and making your own meaning from them will enable you to claim these ideas as your own (Photo 10.2).

A *machine* is any device that helps make people's work easier. But what exactly do we mean by **work**? Work is done when a force is applied to move something. It is the act of applying a force to move an object through a distance. We change an object's position when we do work.

work
The act of applying a force to move an object through a distance.

A **force** is a push or a pull. You encountered the term *force* earlier in this chapter in the discussion of gravity and inertia. Gravity is a force—an attraction, a pull of any object in the universe on any other. You can think of the sun as doing work as it exerts its gravitational pull and helps to keep the planets and other objects in orbit around it. Of course, forces are also produced by people when they use their muscles. When you pull this book toward you and change its position, you are doing work.

force
A physical agency (such as a push or a pull) that tends to cause a change in the position or motion of an object.

Machines help us do work in several ways:

1. By transferring force from one place to another.
2. By increasing the amount of force applied.
3. By changing the direction of a force: for instance, when you pull *down* on a rope to raise a flag *up* a flagpole.

According to MS-PS2-2, *the motion of an object is determined by the sum of the forces acting on it. If the total force on an object is not zero, its motion will change.* This disciplinary core idea for middle school physical science reminds us that a larger force causes a larger change in motion.

Bob Daemmrich/The Image Works

PHOTO 10.2 These students are learning a very practical application of a simple machine. What is this machine called in scientific terms? How does it help?

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One way to study simple machines is to divide them into different types. Let's look at six types that are commonly explored in school science: the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw. These simple machines receive their force mainly from human muscles, like yours. They are devices that are used to get specific tasks done. Although these simple machines are different, remember to look for commonalities among them.

10-5d Lever

A *lever* is a rigid bar that moves around a fixed point, called a *fulcrum*. The seesaw is an example of a lever. So are a crowbar, scissors, and pliers. These types of levers, called *first-class levers*, change the direction of the force. As you apply force in one direction, the object you are lifting or moving goes in the other direction.

Think about being on a seesaw or teeter-totter (Figure 10.3a). As you move down, your partner moves up. To understand why the seesaw is helping you perform work, think about how difficult it would be to lift your partner the same distance without the seesaw.

The seesaw example also helps show how force and motion are related. Your force on the seesaw depends on your weight. Let's say that your partner weighs more than you do. When you first sit on the seesaw, your weight isn't enough to move your partner up. What will you do? You will move to the very end of the seesaw, increasing your distance from the fulcrum; by so increasing the distance, you decrease the force needed to lift your partner.

A *second-class lever* also reduces the force you need to apply, but the force and the object you are moving go in the same direction. The wheelbarrow, a bottle opener, and an oar for a rowboat are examples of these simple systems.

A *third-class lever* supplies a gain in speed and distance. Examples of such levers are a broom, a shovel, and a fishing pole. To achieve greater speed and distance, the third-class lever actually causes a loss in force: As you sweep with a broom, the broom head moves faster and farther than your hands do but with less force.

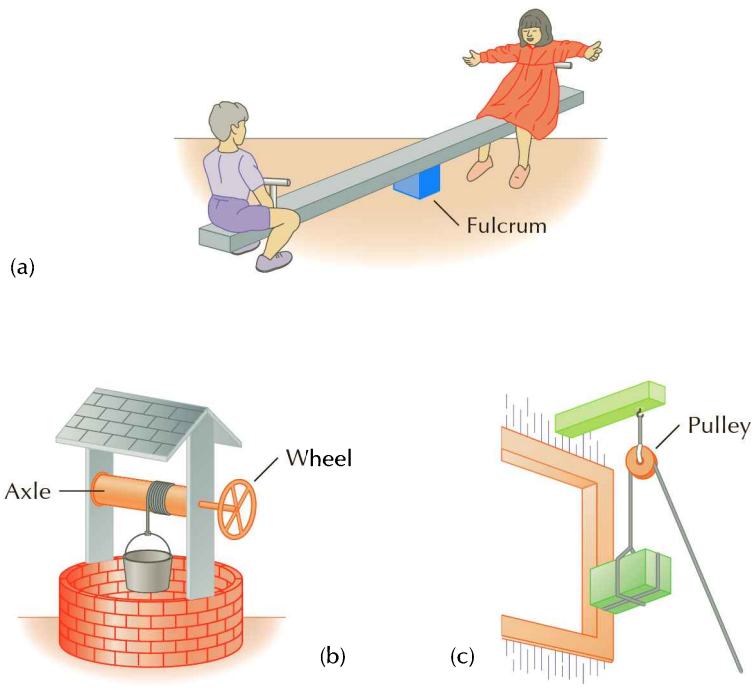

FIGURE 10.3 Simple machines
(a) A seesaw as a first-class lever. Notice how the lighter person can lift the heavier person by sitting farther from the fulcrum. (b) A wheel and axle. (c) A pulley.

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10-5d Wheel and Axle

A *wheel and axle* is like a spinning lever. A large wheel is connected to a smaller circular device, called the axle or shaft. The fulcrum is in the center of the axle and the wheel. Once the wheel turns, the axle turns (see Figure 10.3b). A wheel and axle can change the direction of a force and also amplify the force.

Examples of wheel-and-axle machines that contain complete wheels include the steering wheel in a car, the gear wheels of a bicycle, a doorknob, and a screwdriver. The steering wheel revolves around an axle called the steering column; the bicycle gears revolve around an axle called a shaft; and a doorknob revolves around an axle called a rod. The handle of a screwdriver does more than enable you to hold it. It amplifies the force you use to turn it to drive the screw home! Its axle is the screwdriver blade.

With a wheel and axle, as the wheel rotates it moves a greater distance than the axle but turns with less force. That is, when you turn the wheel, the axle turns with a greater force than the wheel. In this way, a small rotary motion can open a locked door!

Sometimes a crank instead of a wheel is attached to the axle. Wheel-and-axle machines with a crank include a manual eggbeater and a pencil sharpener.

10-6c Pulley

A *pulley* (see Figure 10.3c) is a wheel that turns around a stationary axle. When the pulley wheel turns, the axle does not turn. Usually there is a groove in the pulley wheel so that a rope around the pulley will stay in place. Sometimes there are two or more pulley wheels side by side on the same axle. If the pulley wheel is attached to a stationary point, it is called a fixed pulley.

You use a pulley to change the direction of a force and make work easier. Fixed pulleys are used when raising flags along flagpoles and when pulling curtains or venetian blinds open or closed. A fixed pulley is like a spinning first-class lever. The fulcrum is at the center of the axle. An elevator is a single-pulley lifting machine. The elevator car is raised or lowered by a cable running over a pulley at the top of the elevator shaft.

10-5d Inclined Plane

An *inclined plane* is a slanting surface that connects one level to another level. A hill, a wheelchair ramp, a sloping floor, an escalator, and a stairway are all examples of inclined planes. Moving an object up an inclined plane requires less force than lifting it straight up to a higher position. The longer the inclined plane, the less steep the slope and the less force required. The tradeoff is that, to reduce the force needed, the inclined plane increases the distance traveled.

10-5d Wedge

A *wedge* is a simple machine used to spread an object apart or to raise an object. The wedge is like a moving inclined plane. It has a sloping side, but it is moved under an object or into an object. A typical doorstop is a single wedge. Examples of double-sided wedges are the blade of an ax, a scissors blade, and a plow blade; each of these is sloped on two sides.

A nail is a type of wedge, and so is a pin. Shovel blades can be examples of wedges. A chisel is a perfect example of a wedge. The longer or thinner a wedge is, the greater the advantage in using it.

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10-6f Screw

A *screw* is an inclined plane that winds around and around in a spiral. The spiral ridge of the screw is called the thread. Ordinary wood screws and bolts are examples. Other examples include the caps of jars and bottles, the base of an electric light bulb, and the part of a vise that opens and closes the jaws. Usually another simple machine, such as a lever or a wheel and axle, is used with a screw to reduce the force needed. With a wood screw, for instance, you use a screwdriver; with a vise, you use a handle.

10-5d Compound Machines and Gears

Many of the machines we encounter, like the snow shovel, are *compound machines*. That is, they are made up of two or more simple machines. Consider an ax: its handle is a lever; its blade is a wedge. Here are some other examples:

- A pair of scissors has two levers with wedges for blades.
- The handle of a manual pencil sharpener is a wheel-and-axle system that turns two screws with sharp edges shaped as wedges. The edges act as blades to sharpen a pencil.
- A manual rotary can opener is part wheel and axle and part circular wedge.

As you can see, these are simple systems that combine to form more complex systems, just as our planet–moon system forms part of a larger, more complex solar system and the respiratory system is part of a larger, more complex body system.

A commonly found compound machine is the bicycle. It is a wheel-and-axle machine that uses a system of gears. A *gear* consists of one wheel that is used to turn another wheel. These wheels have saw-like "teeth" on their circumferences that allow the wheels to interact with each other. A chain around both wheels connects them. The chain usually has notches, which fit into the teeth of the wheels.

The bicycle pedal turns a crank that turns a large gear. The chain then turns the smaller gear, and the smaller gear turns the rear wheel, which drives the bicycle forward. Each time the pedals turn the larger gear around once, the smaller gear turns the rear wheel around many times.

Thinking About Systems

Simple Machines as Systems

All machines make work easier for people. Each of the machines discussed in this chapter represents a system—parts working together to perform a function.

A single wedge, for example, is a movable inclined plane. Combine it with a simple lever and you have a shovel! Can you see why these are systems? The lever needs a bar and a fulcrum, working together. The wedge needs a flat slope and an inclined slope. Putting them together, you can clear the snow from your front walk or tend to your garden.

To expand your understanding of machines as systems, ponder these questions:

- Are *you* part of the machine systems described here? If so, how?
- Are there parts of your body that can act as simple machines? Which parts?
- Earlier in this chapter, you saw that the solar system and human body systems have forces that make them work, just as simple machines do. What principles from physical science, life science, and earth science can be applied to *all* of these systems?

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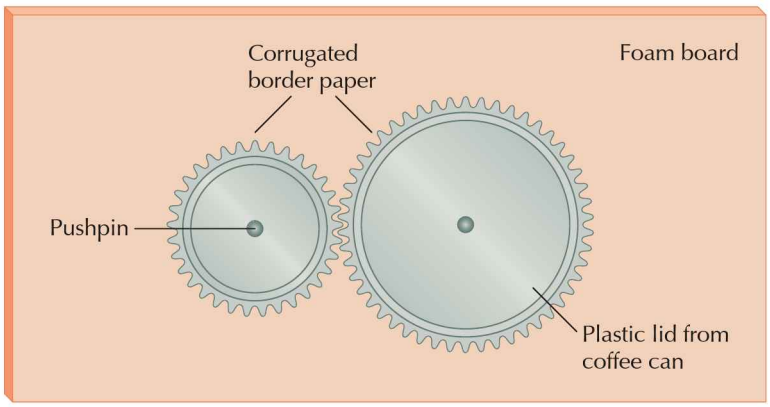

FIGURE 10.4 Simple gear experiment using two sizes of coffee can lids
Using a setup like this, count the number of times the smaller gear turns for each turn of the large gear. Measure the diameters of both lids. Now can you devise a mathematical way of relating the difference in turns to the difference in diameters?

It is fun to explore the relationship between the diameter of the gear wheels and the number of rotations. If you can obtain plastic lids from one- and two-pound cans of coffee, you can use corrugated border paper, a piece of foam board, and a couple of pushpins to make your own model gear system, as shown in Figure 10.4. Glue the border paper trim around the edges of the plastic lids. Place the lids on the foam board so that the border paper "teeth" interface with each other. Press the pushpins through the center of each lid to secure your "gears" to the foam board. Turn the larger gear once and count the number of times the smaller gear turns. Then repeat the experiment by turning the smaller gear once. Measure the diameters of both lids and create your own gear-ratio theory!

10-7 The Earth as a Super-System

Teachers and students explore the interactions of human activities and natural systems on earth through the study of disrupted ecosystems and local habitats as we saw in Chapter 4. In recent years, more attention has been given to the quality of our air, water, and land as we delve more deeply into the effects of human development on the earth's natural systems. The NGSS DCI, MS-ESS3.C: Human Impacts on Earth Systems, states "Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species" (MS-ESS3-3).

When we think of the earth as a system, we must view the planet from its center to the outer limits of its atmosphere, including everything in and on it. In this sense, the earth can be called a super-system: a complex, mixed living and nonliving system with many interacting components, including the atmosphere, the geosphere, the hydrosphere, and the biosphere (Miller & Miller, 2000).

- The *atmosphere* is the layer of gases surrounding the earth and retained by the earth's gravity. About 78 percent of the atmosphere is nitrogen, about 21 percent oxygen, and 0.93 percent argon. Other gases, including carbon dioxide and water vapor, exist in small, variable amounts.
- The *geosphere* is the solid earth that includes the continental and oceanic crust as well as the various layers of the earth's interior.
- The *hydrosphere* includes all water on earth, in oceans, lakes, rivers, streams, soil, groundwater, ice caps, glaciers, and the atmosphere.
- The *biosphere* is the zone of the earth that includes all living organisms. The biosphere distinguishes earth from all other planets in the solar system.

When we develop an integrated understanding of the earth as a system, then we can understand the role that humans have played in modifying the dynamics of the system.

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10-7a The Earth's System and Green Science

The understanding that systems consist of many parts and that the parts usually influence each other underlies the study of environmental science. Something may not work as well (or at all) if a part of it is missing, broken, worn out, mismatched, or misconnected. With these basic concepts, science education can help us to understand the impact of the world's 7.2 billion people and their technologies on the climate, the atmosphere, and other living organisms. Science education may help students learn to live in ways that keep our planet healthy.

The accompanying feature on climate change describes what recent scientific reports tell us about global warming and the connection to greenhouse gas emissions from our cars, our homes, and our industries. When you talk about climate change with students, you should be aware of the way scientists use these key terms:

greenhouse gases
Gases that reduce the amount of heat energy (infrared radiation) that is radiated back toward space when the sun's energy enters the atmosphere and strikes the earth. These gases include carbon dioxide, methane, and nitrous oxide. Many greenhouse gases occur naturally, but they may also be produced by industrial processes. Excess greenhouse gases in the atmosphere can cause average temperatures to climb over time.

fossil fuels
Fuels such as oil, gas, and coal that derive from the remains of plants and animals that lived long ago.

climate
The average pattern of weather for a particular region, measured over a long period of time.

weather
The short-term conditions of the atmosphere in a particular place (compare *climate*).

- As we saw in Chapter 6, **greenhouse gases** are gases in the atmosphere, such as carbon dioxide and methane, that trap the sun's energy and contribute to rising surface temperatures. Greenhouse gases occur naturally and protect the atmosphere from becoming too cold. In excess, however, they trap reflected radiation from the sun and cause unwanted increases in the atmospheric temperature.
- The **fossil fuels** that create greenhouse gases when burned include oil, gas, and coal. These are the remains of plants and animals that lived long ago. Found deep underground, fossil fuels took millions of years to form and thus are not renewable. Once consumed, they cannot be created again.
- **Climate** is the average pattern of weather, taken over a long period of time, often thirty years, for a particular region. Climate depends on the geographic location of the region, its latitude, its terrain, whether it has a persistent ice or snow cover, and its proximity to bodies of water.
- **Weather** describes the short-term conditions of the atmosphere in a particular place.

The same reports that help us understand global warming also offer suggestions for how people may change their impacts on their environment. Clearly, many changes are required at the governmental and institutional level; however, in elementary and middle school science, we can explore areas like conservation, recycling, and the reduction of waste. For example, elementary and middle schools generate a great deal of waste, and students can analyze and monitor that, as you can read about in the *Science Story* about milk waste in Chapter 11. Through a scientific understanding of the effects of fossil fuel burning on the global climate, students can take responsibility for:

- Packing a waste-free lunch.
- Walking or biking to school if possible.
- Using both sides of recycled paper.
- Carpooling when alternative transportation is unavailable.
- Using pencils and rulers made from recycled materials.

Remember that making connections between the scientific concepts and the students' daily lived experience brings classroom science to life.

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The Scientific Consensus on Climate Change

Although the changes in earth's climate have been much debated, most environmental scientists now agree on the following:

- The global climate is definitely warming.
- Most of the temperature rise in the past half-century probably stems from the increase in human-produced greenhouse gases. Mathematically speaking, the chance that natural processes account for the warming is less than 5 percent. Carbon dioxide (CO_2) emissions in the United States increased by about 7 percent between 1990 and 2013. CO_2 concentrations in the atmosphere have increased by 40 percent since preindustrial times.
- CO_2 is the primary greenhouse gas emitted through human activities. In 2013, CO_2 accounted for about 82 percent of all U.S. greenhouse gas emissions from human activities. CO_2 is naturally present in the atmosphere as part of the earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle—both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere.
- Although the changes in average temperature seem small in themselves, they have been accompanied by significant increases in floods, droughts, heat waves, and wildfires, particularly since 1970.
- Other recent phenomena apparently related to warming temperatures include increasing intensity of tropical storms, large reductions in summer sea ice in the Arctic Ocean, large increases in summer melting of the Greenland Ice Sheet, and signs of instability on the West Antarctic Ice Sheet.

Sources: IPCC (2013) and EPA (2016).

10-7a Energy and Matter in the Earth's System

Another way to understand earth as a system is to notice the fluxes of energy and matter that become apparent as we explore water, life, air, and rocks on our planet. Some examples include:

- *Cycles:* how things happen or get used over and over again. Examples include the rock cycle, the water cycle, and the carbon cycle.
- *Flows:* how matter and energy move from place to place. For example, energy moves through food chains and from the sun through living systems during photosynthesis.

This idea of regular patterns on earth leads us to our second major conceptual category for organizing science topics: interactions and patterns of change.

10-8 Interactions and Patterns of Change

Many of the phenomena that we observe on earth involve interactions among components of the air, land, and water, and forms of energy such as heat, light, sound, and electricity. We use the term *interaction* to mean a change in matter and energy. Interactions contribute to many patterns of change on the planet, such as the water cycle and weather; earthquakes and volcanoes; and the rock cycle, weathering, and erosion. As you read about interactions between matter and energy, you may want to ask yourself: What is changing? What is remaining the same?

One of the basic beliefs in science stems from the work of the scientist Albert Einstein (1879–1955). In 1905, he proposed a theory relating matter and

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energy to each other, a theory that many other scientists have tested through their studies of the atom. When such a statement about principles or patterns in nature endures over time and survives consistent tests, we call it a **scientific law**. Earlier, in the section on systems, you read about the law of gravitation. Einstein's explanation of the relationship between matter and energy in ordinary chemical reactions is called the **law of conservation of matter and energy**. According to this law,

scientific law
A statement about principles or patterns in nature, indicating relationships between or among facts. Laws have endured over time and have consistently been tested; but, like theories, they are not absolutely "proved."

law of conservation of matter and energy
The scientific law asserting that matter and energy can be changed into each other but cannot be created or destroyed.

1. Neither matter nor energy can be created or destroyed, but either can be changed into other forms of matter or energy.
2. Matter can be changed into energy; energy can be changed into matter.
3. Therefore, the total amount of matter and energy in the universe is always the same.

This law requires lots of time to think about. Einstein quantified the relationship between matter and energy with his famous *special theory of relativity,* expressed in the equation $E = mc^2$. In this equation, E stands for the amount of energy, m for the amount of matter, and c for the immense speed of light (about 186,000 miles/second, or 300,000 kilometers/second). The equation indicates that the transformation of even a tiny amount of matter will release an enormous amount of energy. I invite you to think about this matter–energy relationship as we explore changes in matter and energy in the following sections.

Different kinds of matter exist and are described by observable properties. **Matter** usually has some mass and takes up space. Air, water, rocks, wood, and metals are examples of matter. People, other animals, plants, the sun, and other stars and planets are also examples of matter. In contrast, **energy** is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another and from place to place (4-PS3-2 and 4-PS3-3). Energy is also thought of as the ability to do work. (Remember, *work* is defined as the process of applying a force to move something through a distance.) Now let's explore the interactions of various forms of energy with various forms of matter.

matter
Anything that has mass and takes up space.

energy
The ability to do work.

10-5d Heat Energy and Matter

Stored-up energy is called *potential energy,* whereas the energy of moving objects is called *kinetic energy.* As we begin the study of heat energy, you will see that it is, in fact, a form of kinetic energy.

Heat energy is really the energy of moving particles. The more heat energy a substance has, the faster its particles move, and the hotter the substance becomes. Remember that there are three main states of matter on earth: solids, liquids, and gases. (Plasma, the fourth state of matter, is the stuff stars are made of.) On earth, the state of matter with the most heat energy is the gaseous state. The particles move fastest in a gas. In liquids, the particles move more slowly, and in solids they move very slowly.

It may be difficult to believe that solids, like your desk, are made of matter that is moving, but indeed that is so. We cannot see the motion, but we know that all matter is made up of atoms and molecules and their own subatomic particles, and that these particles are always in motion.

10-5d Water

When heat energy is added to water, the water becomes hotter and hotter—its particles move faster and faster—until it reaches its boiling point, and then it can change from a liquid into a gas, known as water vapor or steam. This water

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vapor has a greater amount of heat energy than the liquid. In fact, hot steam can cause a more severe burn than hot water because, to become steam, it had to absorb so much heat energy! Technically, steam itself is not visible. We know that steam is present because as it meets the cooler air, it condenses. It is the condensed particles of water vapor that are visible.

Conversely, if we remove enough heat energy, we can cool water and produce a solid. The more heat energy we remove, the slower the particles move, and eventually the water becomes ice. The point at which this happens is the freezing point of water.

physical change
Change in the physical properties of a substance, that is, in the properties we can readily observe with our senses.

When we change water from a solid into a liquid to a gas, we are creating a **physical change**. That is, we are changing only the water's *physical properties*—the properties that we can readily observe with our senses. The distance between the molecules changes: The molecules are closest together in the solid and farthest apart in the gas. But the basic composition of the water does not change: It is still made up of the same arrangement of atoms of hydrogen and oxygen that chemists designate as H_2O.

Similarly, if we tear a piece of paper in half using the force of our muscles, we are changing the size of the paper but not its composition. This is another example of an interaction of matter and energy that produces a physical change.

10-6c Sugar

Sugar is a compound made up of hydrogen, oxygen, and carbon, but its properties do not resemble the properties of hydrogen, oxygen, or carbon. When these three elements combine to form the compound sugar, the elements lose their original properties. In fact, sugar can be thought of as a system in which the parts and the whole do not have features in common.

When sugar is granulated or formed into cubes, we say it is undergoing a physical change; its composition has not changed. If we add heat energy to sugar so that it slowly caramelizes, we are changing it from a solid into a liquid in a process called melting, and that also is a physical change. The sugar still retains the same chemical composition.

But when we add enough heat energy to sugar, we will notice steam escaping from it, and a black carbon-like substance forms. This breakdown in the composition of sugar is called a **chemical change** or a *chemical reaction*. This particular type of chemical reaction is called *decomposition*.

chemical change
A change in the chemical properties of a substance, that is, in the composition of the substance and the way it behaves with other substances; also called a *chemical reaction*.

The *chemical properties* of a substance are those characteristics that have to do with its composition and the way it behaves with other substances. Chemical changes usually produce new substances that have no resemblance to the original substances.

10-5d Bottles and Balloons

Imagine that you have two empty (except for air, of course) soda bottles, exactly the same size. Pour 100 milliliters of water into one bottle and 100 milliliters of vinegar into the other bottle. Place two tablespoons of baking soda into deflated balloons. Hang a balloon over each bottle like a stocking cap. With the help of a friend, simultaneously raise the balloon over each bottle so that the baking soda drops into the liquid.

Hold on! These two bottle-balloon systems produce different reactions when the baking soda reaches the liquid. In the vinegar bottle, there are lots of bubbles, and the balloon inflates. In the water bottle, the baking soda drops to the bottom, and nothing happens to the balloon. If you wanted to get the bak-

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ing soda back, you could slowly allow the water to evaporate. In the vinegar bottle, however, a new substance has formed. Baking soda and vinegar combine to produce bubbles of carbon dioxide gas. The balloon inflates when the carbon dioxide is produced in the reaction.

In what ways are these systems the same? Different? Do you think they look the same initially? How could you tell that one bottle had water and one had vinegar?

10-8e Sources of Heat Energy

In order to better understand heat energy, you may want to think about the various sources of heat energy on our planet:

- Solar energy, or energy from the sun, produces heat energy. In fact, the sun–earth system provides us with our main source of heat.
- The mechanical force of friction produces heat energy. For instance, rub your hands or two sticks together, and you produce heat. This is a transformation from mechanical energy of motion into heat energy.
- Heat energy can also be produced by converting chemical energy. The burning of oil, gas, coal, or wood is a chemical process that releases heat energy.
- Electrical energy can produce heat energy when an electric current flows through thin wires, such as the filament of a light bulb or a toaster.
- The energy stored in the nucleus of an atom, or nuclear energy, can produce a vast amount of heat energy.

10-9 Heat Energy on the Move

Heat energy travels in three basic ways, through the processes of radiation, conduction, and convection.

1. *Radiation. Radiation* is the method of heat transfer that occurs when the sun's energy is transferred to the earth. This heat energy travels to us by radiating through space in invisible energy waves. Heat waves, also known as infrared waves, are part of the *electromagnetic spectrum*. This is a family of energy waves that includes radio waves, light rays, ultraviolet rays, x rays, gamma rays, and cosmic rays. They all travel at the speed of light.

   Radiation as a form of heat transfer should not be confused with other types of radiation, such as radioactive emissions, some of which can be very harmful. The type of radiation that is emitted from high-energy nuclear reactors, for example, is harmful.

2. *Conduction.* Every time we use a potholder or wear shoes on a hot beach, we are protecting ourselves from getting burned by the process of *conduction.* As a substance takes in heat energy, its particles (molecules) move faster and faster and bump into each other. They can also collide with particles of another substance, such as the surrounding air or your own skin. The heat energy is passed along or *conducted* from molecule to molecule.

   In order for heat to move by conduction, two things with different temperatures must be touching. A material that passes heat along well is

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a good conductor. Metals are good heat conductors. Materials that do not allow heat through are insulators. Wool, down jackets, wood, plastic, and rubber are good insulators.

3. *Convection*. The heat transfer that occurs in fluids is known as *convection*. A *fluid* is any substance that flows. Liquids are fluids, and so are gases such as air.

When a gas or liquid is heated, the molecules move more rapidly and spread farther and farther apart. The greater the space between the particles, the more volume the fluid occupies, and the less dense it becomes (see the discussion of density in Chapter 7). For example, air or water that is warmed expands and becomes less dense.

Think of a pot of water heated on a stove (Figure 10.5). The water on the bottom of the pot absorbs heat from the burner and becomes less dense. The water near the top of the pot remains colder and denser. The

Thinking About Interactions

Chemical and Physical Changes

We come across chemical and physical changes all the time in our daily lives. For example, when an iron nail rusts, it has changed its composition and undergone a chemical reaction; this is an example of a chemical change. A new substance is formed: iron oxide—the chemical name for rust.

See if you can figure out whether the following are examples of physical change or chemical change, or both. Remember, science is messy, and neat categories often elude us.

1. Sour milk
2. Burnt toast
3. A ripped skirt
4. A mowed lawn
5. A stained shirt
6. A flowing river
7. Eroded rock particles
8. A weathered building
9. Digestion

Some questions you may ask yourself include:

- Was a new substance formed?
- Was there a change in form, not content?
- How did the change occur?

The answers are provided below.

1. Chemical change, because the composition of the milk is changed.
2. Chemical change and physical change: the bread loses some of its water when toasted and changes color.
3. Physical change: there is a tear in the material.
4. Physical change: the grass is shorter.
5. It depends on the stain! If it is an acid stain, then it could change the composition of the materials; otherwise, it is a physical change in the fabric.
6. Physical change: the water moves but it is still water.
7. Physical change: the particles of rock are the same, only smaller.
8. Physical and chemical change: the composition of the surface is changed, and the color appears different as well.
9. Physical and chemical change, because the food changes in both size and composition as it goes through the digestive system.

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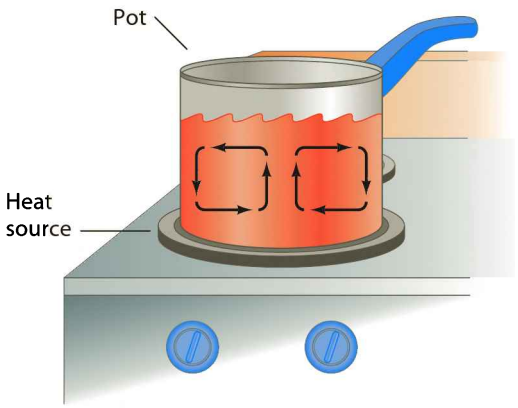

FIGURE 10.5 Convection currents in a pot of water being heated on a burner
Colder, denser water sinks, pushing the warmer, less dense water upward.

denser water sinks, pushing the warmed water upward. Convection, then, is a process by which warmed gases or liquids are pushed upward by cooler, denser gases and liquids. The continuous cycling of these fluids is called a *convection current*.

Lots of people like to say that "heat rises." I remember how surprised I was to learn that heat itself did not magically rise, but that some *thing*—a gas or a liquid—was actually rising. Convection was at work in the story of "The Bottle and the Balloon," in Chapter 2, where we saw a balloon inflated above a bottle that was placed in a pot of hot water. If you have a radiator in your house, you will notice how the warm air rising from the radiator heats up an entire room by setting up a convection current. Some ovens are designed specifically to take advantage of convection currents.

Convection, in fact, is the basis for the earth's system of air and water currents. Uneven heating of the earth's curved surface causes some ocean waters to heat and cool at different rates. The air above these ocean waters heats and cools at different rates as well. The resulting convection currents explain many of our ocean and weather patterns. Even magma, the fluid rock beneath the earth's surface, is heated unevenly. This results in convection currents that contribute to the formation of mountains, earthquakes, volcanoes, and even the spreading of the ocean floor.

Thinking About Interactions

Links between Interactions and Systems

Interactions and systems are linked. When we think of systems, we may ask ourselves, "What are the interactions at work?" When we think of interactions, we may ask, "What system contains these interactions?"

For example, you have just read about convection currents, which are interactions between heat energy and liquids or gases. We could also be describing the operation of a system, for example, a convection oven. All systems rely on interactions between matter and energy.

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10-10 Electricity

electricity
A form of energy produced by a flow of electrons.

In an earlier chapter, you read two stories about teachers engaging their classes in investigations with electrical circuits. You may recall that **electricity** is a flow of electrons. In this section, we will try to delve more deeply into the following:

- What is an electron?
- How is electrical energy a form of matter–energy interactions?
- How do other forms of energy produce electricity?
- How does a generator work?

10-10a The Structure of Matter and the Electron

Much of the history of science has involved the search for the structure of matter. Matter, as you learned in an earlier chapter, is made up of tiny particles called atoms. An *atom* is the basic structural unit of matter—the smallest part of an element (a pure substance) that still has the properties of that element.

We know a great deal now about the complex structure of the atom itself. There are three basic subatomic particles—protons, neutrons, and electrons—and scientists have broken these down into even smaller particles.

Earlier in the book you also read about *molecules*, the smallest particles of a compound that still have the properties of the compound. The tiniest particle of water that still has the properties of water is a molecule of water. There are literally billions of molecules in a drop of water. Compounds are made up of two or more elements. Hence, molecules are usually made up of two or more atoms. Sometimes substances are made up of only one element, and the atoms of these elements form single-atom or diatomic (two-atom) molecules. Oxygen, nitrogen, and neon are examples of elements that can form molecules by themselves, without any other type of atom.

Atoms, of course, are tinier than molecules, and electrons are much smaller than any given atom. An *electron* is a particle with a negative (−) electrical charge. Although they have very little mass, electrons have a lot of energy, and they move around the nucleus (center) of an atom with great speed, approximately the speed of light.

A *proton* is a particle with a positive (+) electrical charge. It is much heavier than an electron, about 1,840 times the mass of an electron, but it also has a lot of energy. Because of its mass, though, it does not move as fast as an electron. The positive charge of a proton is equal in strength to the negative charge of an electron, and the two charges are considered opposite to each other. When many electrons are near each other, they repel each other—that is, push each other away. When protons are near each other, they also repel each other. Protons and electrons, however, having opposite charges, are attracted to each other. When a proton and an electron are near each other, the effects of their charges are neutralized.

Because atoms have the same number of electrons and protons, the atom is neutral, without electric charge. But if there is a loss or gain of electrons, the charge is out of balance, and the atom is no longer neutral. If there are excess electrons, we say the atom is negatively charged; if there are too few electrons, we say the atom is positively charged. An atom with an electrical charge is called an *ion*. Notice that the atom can gain or lose electrons, but the number of protons and neutrons usually remains stable. This is because the neutrons and protons are closely packed together in the nucleus of the atom.

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Neutrons are subatomic particles that have neither a positive nor a negative charge. The mass of a neutron is about the same as the mass of a proton and an electron combined. Scientists believe that a neutron is, in fact, a proton and an electron held together by a small bundle of energy called a neutrino, which has no electrical charge and no mass.

Neutrons and protons are held together in the nucleus of the atom by enormous amounts of energy, sometimes called binding energy. The electrons move around the nucleus of the atom at different distances, called energy levels or orbitals. Thus, an atom's electrons form a sort of hazy electron cloud as they move around the nucleus. Sometimes they are near the nucleus and sometimes they are farther away, depending upon how much energy they have at the moment. (See Chapter 8 for more on electron clouds.)

10-10b Static and Current Electricity

From the structure of the atom, you can see that all matter is electrical in nature. This brings us to the role of the electron in the form of energy called electricity.

Sometimes you can rub certain materials with another material and actually remove electrons from some of the atoms. When the electrons of one material pass to the atoms of another material as they are being rubbed, we may get a "shock." This happens, for instance, when you rub a balloon on a wool sweater. The kind of electricity that has been produced from the force of rubbing is called *static electricity*. Sometimes we say that our clothes feel "static-y."

You've probably also noticed that, after a balloon has been rubbed on a wool sweater, it can adhere to a wall. What is going on? Wool and fur tend to lose electrons when they are rubbed, giving them a net positive charge. The balloon, in contrast, gains electrons and has a net negative charge. When you hold the balloon against the wall, the electrons in the layer of paint on the wall are repelled by the balloon's extra electrons. The paint's electrons move away along the surface, leaving the spot where they originated with a net positive charge. The negatively charged balloon then "sticks" to the wall because opposites attract! For the same reason, little bits of paper are attracted to the charged balloon.

When electricity moves, it is called *current electricity*. Scientists believe that when an electric current is flowing through a material, the electrons flow from atom to atom inside the material. Materials, such as copper wire, that allow an electric current to flow freely through them are called conductors. Most metals are good electrical conductors, just as they are good heat conductors. Carbon, although a nonmetal, can also conduct electricity. Materials that do not allow electrons to flow freely through them are called nonconductors or insulators. Examples of insulators are rubber, many plastics, wood, glass, porcelain, and cloth.

10-10c Energy Transformations and Generators

Electricity is a form of energy and can therefore be produced from other forms of energy. Chemical energy stored in a battery can be changed into electrical energy. Light energy can be transformed into electricity using a photoelectric cell or solar cell. You can even twist two wires together and heat them to produce an electric current; this device is called a thermocouple.

How is the electricity you use in your home produced? In most cases, it comes from a generating plant that takes advantage of the relationship between electricity and magnetism. The basic principle of an electrical *generator* is that electricity is produced by moving magnets around a wire coil—or, alternatively, moving a wire coil between the poles of a U-shaped magnet. A typical generating plant uses a source of heat energy to boil water. The steam from the boiled water turns large wheels called turbines, which then turn the wire coils or the huge magnets of the generator.

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Notice that the electrical generator is a system that produces electrical energy as a result of many interactions between matter and other forms of energy. The mechanical energy of the turbines is needed to produce the electricity. The heat energy of the steam is used to produce the mechanical energy. Electrical power plants use different materials to heat the water; many burn fossil fuels like coal and oil, while others use nuclear power. Some power plants use the mechanical energy of running water to turn the turbines. You may want to visit a local electrical power plant to learn more about how it works.

There are environmental concerns about the ways in which utility plants operate. Those that burn fossil fuels often emit significant amounts of harmful greenhouse gases. Nuclear-powered electrical plants may give off harmful radiation in the event of an accident. In 2011, the 9.0 earthquake in Sendai, Japan, and the tsunami it caused did enormous damage to the cooling systems of the nuclear power plants in that part of Japan. The risk of radiation release remains a serious concern for residents of that area. These systems are often not fully understood by the public, but they present issues that may affect the quality of your life and raise the potential for global warming.

10-11 Light

light
A form of energy radiated by the sun and stars. Light is only the visible part of the electromagnetic spectrum, which also includes many types of electromagnetic waves that we cannot see.

Light is a form of energy that is given out, or radiated, from the sun and other light-producing objects in the form of waves. These light waves are sometimes referred to as radiant energy. Light, like heat energy, is part of a group of radiant energy waves called the electromagnetic spectrum. Among these waves, light rays are the only ones that we can see.

All electromagnetic waves, including light waves, travel at the same speed, approximately 186,000 miles/second (300,000 kilometers/second). You may recall that earlier in this chapter we referred to this enormous speed when we explored the conservation of matter and energy. Light travels so quickly that it crosses earthly distances in what appears to be an instant. Light energy makes it possible for us to see the things around us—and to see them without any noticeable delay.

Measured against the vastness of outer space, however, the passage of light is not so instantaneous. Even at its enormous speed, the sun's light takes eight minutes to reach the earth. This is useful for us to reflect on, because it helps us imagine the immensity of space. If the sun were to stop shining, it would not go dark in our sky for eight minutes!

The distance light travels in a year is a called a *light-year*, and it equals about 6 trillion miles, or 9.5 trillion kilometers. The light-year is used as a measure of distance when we are referring to the great expanses of the universe.

Like waves in water, light waves move up and down as they move forward. But light requires no medium to travel in; it can travel in a vacuum, such as the vacuum of outer space. In addition to its wavelike nature, light also acts like a stream of particles. Scientists have dubbed these particles *photons*, and they have learned that photons are a lot like little bundles of energy.

10-11a Sources of Light

The sun is our natural source of light. It produces energy by changing the atomic nuclei of its atoms. This process of *nuclear fusion* produces enormous amounts of solar energy. The energy is released as light and as all the other waves of the electromagnetic spectrum.

One common alternative conception about the sun is that it is "burning." In fact, there is no fire, but there is enormous heat (10,000 degrees Fahrenheit, or 5,538 degrees Celsius) and explosive activity. The sun is made of plasma, like

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other stars, and it produces its energy in the same way as other stars. The moon and planets do not produce their own light. Rather, they shine by the process of reflection—the sun's light bounces off their surfaces.

Besides the sun's natural light, we have many artificial sources of light. These include candles, kerosene or gasoline lamps, and various forms of electric light.

10-11a Light Energy and Matter

For us to see an object that does not produce its own light, there must be a source of light, the light must strike the object, and the light must bounce off or be *reflected* from the object and then travel to our eyes.

Opaque materials do not allow light to pass through them; instead, they reflect most of the light that strikes them. *Transparent* and *translucent* materials, in contrast, allow most of the light striking them to pass through. Still, some light is reflected and some is absorbed by the material.

Light travels in straight lines; it does not go around corners. When light is reflected, its direction changes, but it still travels in a straight line. A mirror is a good example of a shiny, reflective surface that allows us to experiment with beams of light and watch the direction of reflected beams. Try shining a light at a mirror and studying the way it reflects (Figure 10.6a). Enough experiments of this sort will lead you to believe that the angle at which the incoming light ray hits the mirror is equal to the angle at which it is reflected. This happens only on smooth, polished surfaces, however. Rough surfaces reflect rays of light in an irregular way so the light scatters.

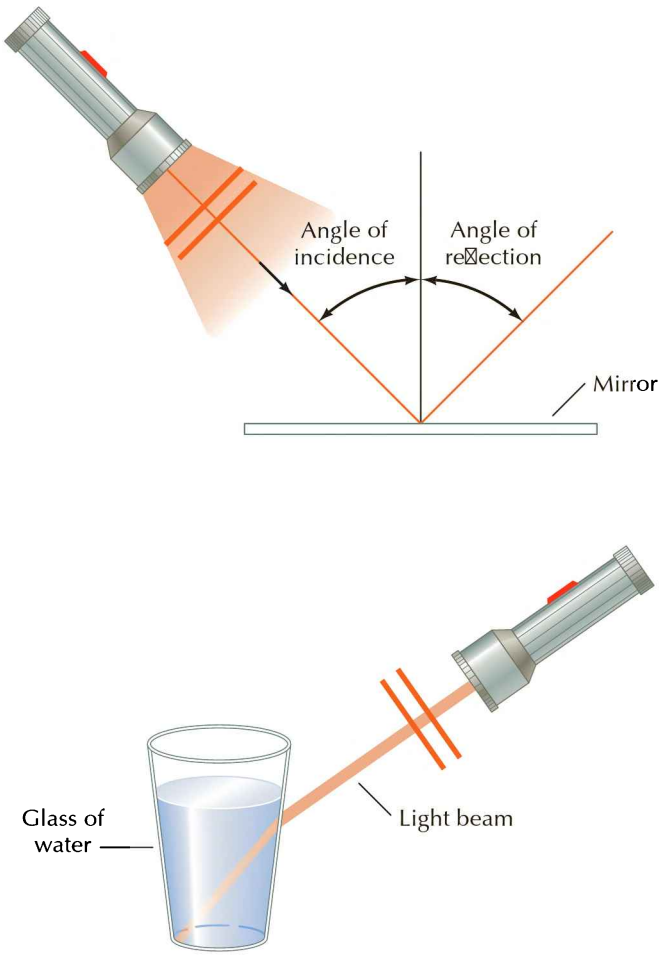

FIGURE 10.6 Reflection and refraction of light
(a) When light strikes a mirror or other smooth surface, the angle at which it bounces off (angle of reflection) equals the angle of the incoming ray (angle of incidence). (b) Passing from one medium to another of different density, light refracts (bends).

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Thinking About Interactions

Making Connections: From Electricity to Heat and Light

Many everyday household objects work by converting electricity into heat energy. These include electric hair dryers, toasters, coffeemakers, irons, ranges, and heaters.

You may notice that wires get warm when electric current flows through them. Often, the thinner the wire, the hotter it gets, until it begins to glow. Can you think of how this phenomenon is applied? A common light bulb works on just this principle, converting electricity into heat and light energy.

The filament in a regular light bulb is made of tungsten, which does not melt when it gets very hot. Instead, it glows, in a process called incandescence. Hence, in the system of a light bulb, there are interactions between electrical and heat energy and metal wires to produce light energy.

Oxygen in the air reacts with metals, as in the process of rusting. If this occurred with the tungsten in a light bulb, the bulb would not last long. Therefore, in the space inside the bulb, there is no regular air, just a gas such as argon, which does not react with the tungsten. See Chapter 9 for more about light bulbs.

When light rays travel at a slant or angle from one transparent medium, like air, into another, like water, the rays are bent or *refracted;* that is, they change direction. If you shine a narrow beam of light into a clear glass of water at an angle (see Figure 10.6b), you can see the light beam bending as it passes through the glass and water. If you look closely at the surface of the water, you will notice that the beam bends at the point where the medium through which it is traveling changes.

When light rays are bent, they can magnify an image, making it appear closer. Conversely, if they bend differently, they can make an image seem farther away. This is one of the principles behind the construction of eyeglass lenses as well as microscope, binocular, and telescope lenses. By refracting light in a precise way, lenses can help us see distant objects or bring blurry ones into better focus.

10-11c Color

spectrum
The band of colors seen when visible light is separated into its component wavelengths, as in a rainbow. The *electromagnetic spectrum* also includes other forms of electromagnetic radiation that we cannot see, such as ultraviolet light, infrared light, radio waves, gamma rays, and cosmic rays.

Have you ever held up a glass or plastic prism to a narrow beam of light? If you do so, you will notice a band of colored lights called the **spectrum**. The spectrum of visible light includes red, orange, yellow, green, blue, indigo, and violet. White light is actually a mixture of these colored lights of the spectrum.

The colors that make up the spectrum have different wavelengths. *Wavelength* refers to the distance between corresponding parts of two of the light waves (Figure 10.7a). Violet light has the shortest wavelength, and red light the longest. When white light enters a prism, the colors with the shorter waves are refracted (bent) more than are the colors with the longer waves (see Figure 10.7b). The seven colors of white light thus are separated according to how much they are refracted as they go through the prism.

A rainbow is a spectrum that is sometimes produced when the sun shines immediately after a rain shower. The water droplets in the air act as tiny prisms, breaking the sunlight into a spectrum in the form of a beautiful arch. If you create a spray with a garden hose, standing with your back to the sun, you can make an artificial rainbow.

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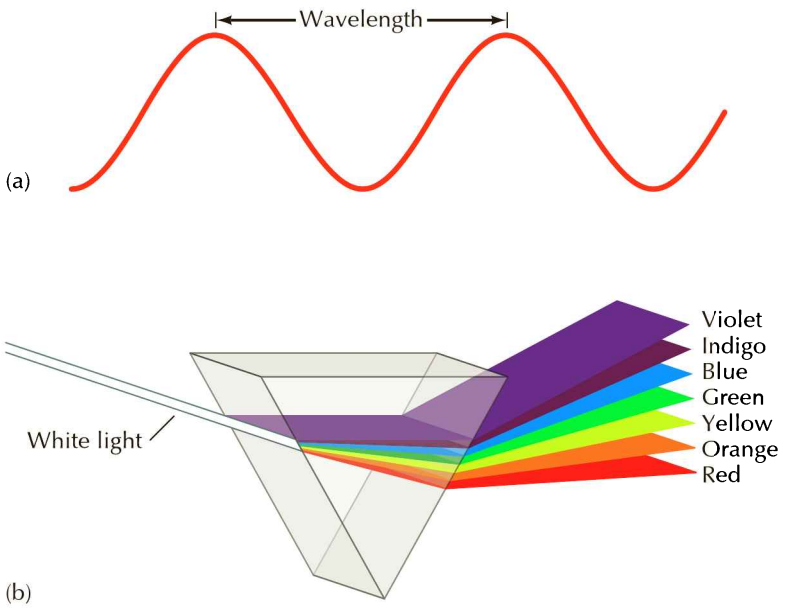

FIGURE 10.7 Color properties of light
(a) The meaning of wavelength. (b) Refracting different wavelengths by different amounts, a prism separates white light into its component colors.

10-12 Sound

sound
A form of energy that is produced by objects moving back and forth or vibrating.

Sound is a form of energy that is produced by objects moving back and forth or vibrating. The vibrations of material objects cause sound, so when the vibrations stop, the sound stops. Here we see an intricate interaction between matter and energy.

Like light, sound energy travels in waves. Unlike light, however, sound cannot travel in a vacuum. When your alarm clock rings across the room, the vibration of the ringer causes molecules in the air to vibrate. The air molecules pass the energy along, coming closer together and then stretching farther apart in a wave motion until the vibrating air molecules reach your ears. Because sound travels quickly, you hear the alarm clock in a fraction of a second.

10-11a The Speed of Sound

Sound usually reaches us by traveling though the air, but it can also travel though liquids and solids. Sound travels best through materials that have more closely packed particles—in other words, through denser materials. Sound travels through air at a speed of about 1,100 feet per second, or about 1 mile in 5 seconds (1 kilometer in 3 seconds). In ocean water, sound travels more than four times faster than in air (about 4,800 feet/second). In steel, sound travels more than 15 times faster than in air!

You can see why sound cannot travel in a vacuum; there are no molecules in a vacuum to carry the vibrations. You can also notice the huge difference between the speed of sound in air and the speed of light: approximately 1,100 feet per second versus approximately 186,000 *miles* per second. Think about how we notice this difference during a thunderstorm. The sound we know as thunder is caused by lightning passing through the air. The lightning makes the air heat up and expand, and this produces giant vibrations in the air that travel toward us as sound waves. But even though the thunder and lightning happen at virtually the same time, we always see the lightning first and then hear the thunder. This is because light travels so much faster than sound.

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10-12b Characteristics of Sound

Experiments with sound reveal that you can vary the properties of materials to produce different types of sounds. For example:

- *Amplitude or intensity.* The loudness or softness of a sound, called its amplitude or intensity, depends on the strength with which the sound-producing object is vibrating.
- *Pitch.* The highness or lowness of a sound, known as the pitch, depends on the rate at which the object is vibrating. The more vibrations per second, the higher the pitch of a sound. The fewer vibrations per second, the lower the pitch. The rate of vibrations is also called the *frequency.* The normal human ear can hear sounds with frequencies ranging between 20 and 20,000 vibrations per second. Dogs can hear higher sounds—that is, sounds with a frequency of more than 20,000 vibrations per second.
- *Quality.* When objects vibrate, they generally send out a mixture of frequencies, and the particular mix determines what is called the quality of the sound. That is why a trumpet sounds different from a violin even when they both are playing the same note. In addition to the main frequency, each instrument is actually producing a set of overtones, or additional frequencies, that combine to give the sound its quality.

10-11c The Human Voice

Humans produce sound by using the larynx or voice box, which is located at the top of the trachea (windpipe). Stretched over the top of the larynx are two thin but strong bands of tissue called the vocal cords. When air from the lungs is blown through the narrow slit between the vocal cords, the cords vibrate and produce sounds.

Thinking About Interactions

Sound Energy and Musical Instruments

Consider a wind instrument—what interactions does it use to create a sound? Basically, the instrument holds a column of air that is made to vibrate, either by blowing into it, as with a saxophone or clarinet, or by blowing across it, as with a flute or piccolo.

In a woodwind instrument like a clarinet, you blow on a thin piece of wood or plastic, called the reed, which is used to make the column of air vibrate. Pressing the keys or covering the holes changes the length of the column of air and therefore changes the vibrations per second and the pitch of the sound produced. A shorter column of air vibrates faster than a longer column of air. Hence, the shorter the column of air, the higher the pitch.

How do you think the amplitude of the clarinet is changed? That's right—by blowing harder into the mouthpiece and causing the reed to vibrate with greater intensity.

In a percussion instrument—drum, xylophone, wood block, triangle, or cymbals—striking the instrument with another object produces sound. For the xylophone, the shorter the bar, the greater the number of vibrations and the higher the pitch. For drums, the thinner and tighter the covering, the greater the number of vibrations and the higher the pitch. Think about this: Can a drummer change the pitch of a drum's sound without altering the drum's covering? (Hint: Is the membrane that covers the drum equally tight all the way across?)

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Muscles attached to the vocal cords make them tight or loose, and in this way they control the pitch of your voice. The tighter the cords, the faster they vibrate, and the higher the pitch of the sound you produce. The same is true for a tighter violin string; it, too, will have a higher pitch from vibrating at a greater frequency.

Men's vocal cords are usually longer and thicker than women's, and they do not vibrate as fast. This explains why men tend to have deeper voices than women.

10-13 Magnetism

Earlier in this chapter you saw that a force is essentially a push or a pull. Usually a force causes a change in the position or motion of an object. Gravity, for example, is the force of attraction between objects in the universe. The gravitational attraction between objects is one of the causes of the kinetic energy that keeps the planets in motion around the sun.

magnetism
A force produced when an object exerts an attraction for materials made of certain metals, such as iron, steel, cobalt, and nickel.

Magnetism is another important type of force. It is produced when an object exerts an attraction for materials made of certain metals—iron, steel, cobalt, and nickel. These metals are called magnetic materials. There are two kinds of magnets, human-made and natural:

- Natural magnets, found in the ground, are called lodestones. They contain a mineral called magnetite and look like irregularly shaped rocks.
- Human-made magnets are made from iron, steel, cobalt, and nickel and are named for their shapes: bar magnets, rod magnets, horseshoe magnets, and U-shaped magnets (Photo 10.3).

The force of a magnet is strongest at its ends, which are called the poles of the magnet. When magnets are allowed to swing freely, their poles are attracted to the north or the south of the earth and therefore are called north-seeking or south-seeking poles. When the poles of two magnets are brought near each other, like poles repel each other and opposite poles attract. That is, two north poles tend to push each other away. So do two south poles. But a north pole and a south pole tend to pull each other closer. This is similar to the attraction and repulsion of electrical charges. In fact, magnetism and electricity are closely related.

Tony Freeman/PhotoEdit

PHOTO 10.3 This student observes the effects of magnetism passing through paper.

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10-12b Electromagnets

When an electric current passes through a wire, a *magnetic field* is created around the wire. This means that the space around the wire can act like a magnet. This effect is strengthened if the wire that carries the electricity is wrapped into a coil. If you then place a piece of iron inside the coiled wire, you make an even stronger magnet, called an *electromagnet*. The strength of this system can be increased by increasing the number of coils of the wire and by raising the strength of the electric current through the wire.

Like other magnets, an electromagnet has two poles, and it attracts magnetic materials such as iron and steel. But an electromagnet is a temporary magnet—its magnetism can be turned off by breaking the electric circuit.

The ability to create magnetic force with an electromagnet has many practical applications. We use electromagnets in devices ranging from telephones to radios, televisions, computers, motors, cranes, and generators (see the explanation of an electrical generator earlier in this chapter), to name a few.

10-12b What Causes Magnetism?

What, you may wonder, are the causes of magnetism? Where does this mysterious force of attraction come from? Scientists are not sure, but they believe the answer lies with the movement of electrons in the atoms of magnetic materials.

Electrons spin as they revolve around the nucleus of the atom. Each spinning electron acts as a tiny magnet. In nonmagnetic materials, the number of electrons that spin in one direction is equal to the number of electrons that spin in the opposite direction. This cancels out their magnetic effects. In magnetic materials, there are more electrons spinning in one direction than in the opposite direction. It is believed that this imbalance of electrons spinning in opposite directions gives rise to magnetism in the material. This also explains why few naturally occurring materials are magnetic.

10-11c The Earth as a Magnet

The earth behaves as if it were a huge magnet, with a north magnetic pole and a south magnetic pole. This is because the deep interior of the earth, known as the inner core, is made up of iron and nickel. The magnetic field of the earth even extends beyond the planet itself.

When you use a compass to discover which direction you are going, you are relying on the earth's magnetism. Because the compass needle is magnetized, one end points toward the earth's north magnetic pole. Although the earth's north and south magnetic poles do not correspond exactly to the north and south geographic poles, they are close enough for most purposes—especially when you are lost in the woods.

10-14 From Content to Curriculum

curriculum
A plan of studies that includes the ways in which the instructional content is organized and presented at each grade level.

From the sampling of science content in this chapter, you can see the richness of the topics that students explore and the importance of the disciplinary core ideas they investigate. But how, you may be wondering, do schools and teachers fit all these topics and ideas into a specific curriculum that meets the needs of students?

The word *curriculum* derives from a Latin term meaning "running course." In science teaching, we usually think of the **curriculum** as a plan of studies that includes the ways in which the science content is organized and presented at

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each grade level. It is not merely a list of topics but an organizational scheme that describes the activities used to facilitate the presentation of the content. Often schools use a list of topics as a *summary* of the science curriculum.

In addition to this *formal* science curriculum, good teachers make use of an *informal* curriculum based on the students' daily lives, as you saw in Chapters 2 and 4, and that you will see in Chapter 11. The informal curriculum includes everyday, often unexpected, topics that arise as a result of living in a given geographic environment or of exposure to a newsworthy science topic. An example is Mr. Wilson's use of icicles to teach melting when the ice storm blanketed the area in which his school is located. The ecology projects at the middle school where rain gardens are planted are another example of the informal science curriculum merging with the formal curriculum. Often, formal and informal science curriculum topics merge. For example, if a class in a seaside community is studying the oceans as a formal unit, the teacher and students can find many opportunities to incorporate aspects of their daily lives into the formal study.

A few years ago, I saw a fifth-grade geology curriculum designed by a school in a shore community of Long Island, New York. It had an extensive section on sand, including required reading about the sands of the Sahara Desert. This reading segment was part of the science textbook that had been purchased by this school. Certainly, the Sahara, being the world's largest desert, was of interest, but it was unlikely that students could explore it directly. Unfortunately, the curriculum offered the students no direct access to sand, even though there was a beach full of it—directly accessible and relevant—down the street from the school. The locale and geography of the school should become relevant to the curriculum, as we saw in Part 2's science stories.

This story of the Sahara desert sand illustrates the importance of using many criteria to design a curriculum. Also remember the key question, "Who are my students?" Whatever the formal curriculum dictates, answering this question will help you to make connections to the lived experiences of your students.

10-15 Who Creates the Curriculum? National Influence and Local Control

In American public education, matters of curriculum have traditionally been the prerogative of local school districts. During the past three decades, however, there has been a great deal of national concern about the competencies and academic performance of students. The publication in the 1980s of reports like *A Nation at Risk* (National Commission on Excellence in Education, 1983) and *Educating Americans for the 21st Century* (National Science Board, 1983) alerted the public to the perceived need to address higher standards in American public education. The subsequent "standards movement" has resulted in national standards for several areas of education, including science.

The *National Science Education Standards* (National Research Council, 1996) and the *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993) represented the work of teacher educators, scientists, and classroom science teachers from all over the world. The intent was to provide educators with a way of thinking about the importance of scientific literacy in today's world. **Scientific literacy** refers to an individual's ability to use scientific information to make choices and to "engage intelligently in public discourse and debate about important issues that involve science and technology" (National Research Council, 1996, p. 1). Both documents argued that such literacy should be the major goal of science education.

scientific literacy
The ability to use the processes of science to make important life decisions; in particular, the ability to explore a problem through careful reasoning.

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The Next Generation Science Standards (2013) took this goal further by establishing standards for science education at the nexus of three dimensions: science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCs). These current standards invite science teachers to consider not just the what, but the how and the why of their science units in the hopes that students will be able to defend and explain their thinking and establish accurate representations of the natural world. In this way, true scientific literacy can emerge. The NGSS are filled with student performance expectations, but they are not a curriculum. Creating curriculum from the standards requires that all three dimensions be part of all units developed for the elementary and middle school curriculum. The science concepts described by the DCIs in life, physical, and earth and space science build coherently from kindergarten to grade 12. They are useful for planning coherent curriculum in each of the topic areas. Keep in mind, too, that topic selection is only part of curriculum construction. To develop a curriculum, educators also need to explore related activities, such as connections with literature, mathematics, technology, and social studies.

10-11a The STEM Education Movement

Recently, there has been a significant movement to make connections among science, technology, engineering, and mathematics education. The acronym STEM represents that movement and makes a lot of sense. Many of the stories in Part 2 of this book relate to STEM projects. For example, when middle school students design and construct model atoms, the principles of engineering design, science and technology, and mathematics are very connected. STEM stresses the fact that mathematics, science, engineering, and technology are interdependent human enterprises. To promote this integration, the STEM approach often uses computer technology (T) as a tool for brainstorming, doing research, modeling outcomes, creating designs, and presenting information.

10-12b STEM and Group Projects

Students who are engaged in STEM activities also tend to be involved in some form of project-based learning in which they use science ideas or mathematics ideas to solve a problem. Often this problem relates to a *design challenge*, like the one you read about in Chapter 8, where the students in Ms. Murray's class were asked to design and build models of atoms. Engineering design is a special way of engaging students in doing their own thinking and giving them the chance to direct their own learning. Central to STEM is the understanding that students become active learners when they are engaged in experiences related to a meaningful context—a larger purpose that stimulates a need to know and encourages the students to acquire skills to solve a problem.

Working in cooperative learning groups, students engage in brainstorming and do background research in order to plan for the implementation of their design. This group process is very important to STEM learning. It requires that students work together to reach the best solution to their design challenge.

10-10c The Impact of STEM

Movements to create STEM learning encourage problem-solving investigations with respect to the following criteria:

- What is the nature of the problem-solving activities in science?
- Where does mathematics present itself in these activities?

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- Are students expected to design a process or a product as part of their investigations?
- What is the nature of students' access to technology during their investigations?
- How are science ideas linked to mathematics and technology ideas?

In this text, you have seen several examples of STEM investigations. In Chapter 7, when Ms. Drescher's students used their understanding of the differing densities of three liquids to design a liquid-display toy, all four components of STEM problem solving—mathematics, science, engineering design, and technology—came into play. In Chapter 8, when students designed a model solar system, they used mathematical analysis of the planets' relative sizes and distances to construct a model that accurately represented the planets in relation to the sun. During this project they employed various kinds of technology, including the WorldWide Telescope. Some of Ms. Travis's students in Chapter 9 designed a blinking lighthouse. They used the science ideas behind series and parallel circuits to light their model, and they used mathematics to determine the scale of the different sections. In Chapter 11, we will examine two projects that use STEM education to guide their development. Ms. O'Connor's second-grade class designs a magnetic car, and Ms. Rhodes's fourth-grade class solves a milk-waste problem.

10-16 Developing Curriculum Units

After reading about standards, frameworks, and the creation of curricula, you may still be puzzled about how schools and teachers get from these broad definitions of expected learning to specific plans for classroom teaching. Usually, this is done by developing curriculum units.

unit of study
A segment of the curriculum that includes several lessons designed around a central theme or topic.

Typically, a **unit of study** includes several lessons that are designed around a central theme or topic. An individual lesson on earthworms, for example, could fit within a unit on classifying vertebrates and invertebrates.

A unit plan usually consists of the following:

- The disciplinary core ideas behind the unit
- The science and engineering practices that activities require
- The specific lesson plans for the unit

Sometimes, unit plans also include a description of the assessment strategy for each unit. We will address several types of assessments later in Chapter 13.

10-16a Aligning a Unit of Study with the NGSS

Teachers are expected to link their units of study to specific science concepts. This process involves the following steps:

1. Identify the topic and its relationship to life, physical, or earth science.
2. Identify the DCIs behind this topic.
3. Explore activity books and other resources relating to the topic.
4. Design lessons that allow students to examine their own ideas and permit the teacher to extend the activities as needed. Make sure the students are engaged with several SEPs.
5. Indicate if there are connections with engineering design, mathematics, technology, literature, and social studies.

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10-12b Selecting Activities

If you are selecting activities for a unit, you should follow the same criteria described throughout this book. Ask yourself questions like these:

- Does the activity lend itself to individual thinking and problem solving?
- Does the activity engage students in several SEPs?
- Does the activity match the science idea expressed by the unit?
- Are the materials accessible?
- Do the students have the opportunity to plan and create?

You are looking for science activities that encourage individual explorations of phenomena. Commercial materials and kits can be useful as long as you frame the activity in a way that allows students to make decisions about the plan for their investigations.

10-10c What Is Missing?

When you rely solely on one standard or framework or commercial product to guide your school's or your class's science curriculum, you miss a great deal of the local influence that ought to contribute to the students' science experiences. Who your students are, how they experience nature, where they live, what region of the country your school is located in—all of these considerations should help you frame your units of study.

Remember, also, to learn about what kinds of personal lives your students have. Are they hungry? Poor? Overindulged? Exceptional? Middle class? How will you use science curriculum to help students make meaning in the context of their own lives? That is the major role of your science curriculum: to engage students in their own learning, to relate science experiences to their lives, and to help them explore and draw conclusions. Certainly, national and state documents should help you understand the range of topics and ideas that are appropriate. But what is best for *your* students remains a local decision.

Curriculum—any curriculum—is a lifeless document. You, the teacher, give it life when you use it to guide your students' experiences.

10-16a A Checklist for the Science Curriculum

The following checklist may help you ask the right questions when evaluating a science curriculum:

- What is the role of scientific investigation in the curriculum?
- Are there earth and space science, life science, and physical science topics at each grade level?
- Do your science units have implications for green science, the study of how humans interact with their environment?
- Are technology, mathematics, and engineering design challenges incorporated into some of the science activities?
- Where are the connections to other subjects, such as social studies and literature?

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- Do the topics build coherently from lower to higher grades? Are there learning progressions?
- Are there topics that have local geographic connections and personal relevance for the students?
- Are the topics explored in depth?
- Is there room for informal science experiences?

If you are involved in creating the curriculum, you should ensure that these questions are answered as you plan. If you as a teacher are working with a curriculum designed by others, these questions can help you to identify its strong points and weak points and to decide when and how to supplement the formal curriculum with informal experiences.

In the next chapter we will examine what integrating other discipline areas "looks like" when teaching elementary and middle school. Because many middle school grades are often departmentalized, with students moving from one subject to another, integrating science across disciplines is a bit more challenging but, as you will see, very doable!

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CHAPTER 11

Surrounded by Science: Science Connections Across Disciplines

Next Generation Science Standards

- **Crosscutting Concepts:** 1, 2, 3, 6, 7
- **Disciplinary Core Ideas:** 3-LS4-4, 3-PS2-3, MS-PS1-1, HS-PS1-1, HS-PS1-8, HS-PS4-5
- **Science and Engineering Practices:** 1, 2, 3, 4, 5, 6, 7, 8

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 11-1 Discuss the importance of a multidisciplinary approach to learning science.
- 11-2 Write a dialog poem about a science concept.
- 11-3 Relate the milk-waste project to the effect of arguing from evidence.
- 11-4 Discuss how engineering design helped students learn more about magnetic forces.
- 11-5 Analyze how STEAM can benefit STEM education.
- 11-6 Examine how making connections to other disciplines enhances students' scientific understanding.

Reflection To Think About:

- Do you ever express your understanding of an idea by writing a poem?
- Have you ever been engaged in project- or problem-based learning?
- Can you imagine second graders designing a toy car?
- How would you study a famous artist's painting to learn if it is the real thing?

As a child, I loved picture books, but it was not until I began teaching high school science that I discovered my love for them again! You may be wondering how I had the nerve to walk into tenth- and eleventh-grade classrooms with picture books; however, I often saw a connection between some image and thought in the story and an introduction to the science topic I was hoping the students would learn. As adult as they believed themselves to be, they loved when I started a lesson on occasion with a favorite picture book. You may recall the story from Leo Lionni's *Fish Is Fish* (1970). It conveys how the minnow in the pond pictured everything the frog was saying about people in terms of the only thing the minnow knew—being a fish! As you read further in the story you see that the fish heaves himself outside the pond to discover the world, only to learn, all too quickly, that he could not breathe. Luckily, the frog nudged him back into the pond just in time. The differences between fish and frogs are profound and represent a link on the evolutionary chain—from the vertebrate group of fish to the vertebrate group of amphibians. While amphibians lay their eggs in water, the adult lives on land, and hence amphibians begin life as organisms that can breathe in water and develop into organisms that can only breathe on land. It is exciting to introduce this concept with children's literature. You will find that students of all ages love connections to literature.

In this chapter, we examine the ways that science ideas emerge in and through other disciplinary areas of study and, while we revisit STEM education, we also explore the use of other areas of study to express and apply our understanding of science concepts.

11-1 The Importance of Interdisciplinary Connections

dialog poem
A poem written in two or more voices that represent multiple perspectives on a topic or a concept. May be used to assess understanding of a science concept.

We live in a global village, and our electronic connectivity has produced great changes in the way we communicate and learn about ourselves and our world. Although subject areas remain segregated in most middle and high schools, there is, as we noted with STEM education, a movement to find the connections between disciplines and foster meaning with those links. In science, this is particularly important because it helps students to *apply* what they know to a new context. The very process of applying what they know often helps students to clarify the meaning of the concept. By teaching our students that they can use their understanding and knowledge of one discipline to solve problems in another, we extend their thinking and enhance their creativity.

Dialog poems are poems written to be read aloud by two readers at once—one taking the left hand part, the other taking the right hand part. It is

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most useful when students write them and perform them for the class. This is what happened to the poems in this chapter—they were written and performed by students in a science class to express their understanding of the science concepts.

11-2 Making Meaning with Dialog Poems

The first time I read a dialog poem was in a book called *Joyful Noise: Poems for Two Voices* by Paul Fleischman (1988). The poem, called *Honeybees,* has two voices—one for the worker bees and one for the queen.

On each line of the poem, the reader learns something about the worker bee and the queen bee "in its own voice." After reading the poem in two voices, I learned so much about honeybees that I decided to ask my students to write dialog poems to express their understanding of science ideas. The following poem is a way two fourth graders expressed the differences between solids and liquids:

Solids and Liquids

I am matter.	I am matter.
I am a solid.	I am a liquid.
I have a definite shape.	I take the shape of my container.
I am rigid.	I can flow.
My molecules are close together.	My molecules are farther apart.
Sometimes, I can become a liquid.	Sometimes, I can become a solid.
As I become a liquid, I take in lots of heat—	As I become a solid, I lose lots of heat—
NOW I am a liquid.	NOW I am a solid.

What might the poem sound like in three voices? You may want to think of a third voice as a gas! Clearly the science ideas behind the poem relate to the properties of different states of matter and could be used with Mr. Wilson's students or Ms. Hager's students. Let's examine a more sophisticated example using the properties of green plants and many animals and exploring what it means to be alive.

I AM LIVING

The following poem in three voices is used by many students who study the properties of living and nonliving things. Many alternative conceptions are clarified by this poem. See if you can find them.

I am an animal.	I am a plant.	I am a rock.
I am living.	I am living.	I am nonliving.
I take in oxygen.	I take in carbon dioxide.	I do not breathe.
I need water to survive.	I need water to survive.	I don't need water to survive.
Feet and muscles help me move.	Wind helps me move.	Sometimes, water helps me move.
I get my food from other living things.	I make my own food.	I don't need food.
With time, I grow bigger, smarter and stronger.	With time, I grow bigger and stronger.	With time, I grow smaller.
A mate helped me reproduce.	A bee helps me reproduce.	I get no help! I don't reproduce.

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I have a brain.	I do not have a brain.	What's a brain?
Someday I will die.	Someday I will die.	I could last forever.
I AM AN ANIMAL.	I AM A PLANT.	I AM A ROCK.

Consider the science ideas or core concepts visited by this poem. Although broadly termed, "Animal" in this poem refers to vertebrate animals: fish, amphibians, reptiles, birds, or mammals. The "Plant" in the poem refers to green plants that make their own food and relates to photosynthesis, the process Ms. Fraser discussed when her third-grade class began germination bags with their seeds, as we explored in Chapter 6. Many young students believe that plants get their food from the soil; however, green plants make their own food through photosynthesis. Photosynthesis is the process by which green plants use carbon dioxide from the air and water from the soil, in the presence of sunlight, to manufacture molecules of glucose. Glucose is a simple sugar that the cells of the plant use to make energy so the plant can carry on its functions, including growth. Green plants give off oxygen, the gas in the air that the animal in the poem takes in! This exchange of materials is central to understanding how living things function and how they are distinguished from nonliving things. This poem also addresses the process of weathering and erosion as the rock may get smaller with time due to the forces of weather or the effects of river and stream water carrying the rocks along with them. Weathering occurs when rocks are worn away by the effects of wind, rain, snow, or ice. Erosion is the process by which rocks and smaller particles are transported by bodies of water. In both cases, the rocks "grow smaller." Concepts of pollination and reproduction are addressed when the rock clearly states, "I don't reproduce." The plant in this poem needs a "bee," referring to pollination, and the animal is this poem needs a mate, referring to sexual reproduction. Although simply stated, the dialog poem in three voices applies several core concepts in science and is wonderful language arts integration.

Ms. Sloane's fourth-grade class worked with earthworms, invertebrates with their hard parts on the inside. Imagine how useful it would be to have a dialog poem comparing vertebrates and invertebrates. Think about other science topics from Chapter 10 that could be applied to a poem in two or three voices!

11-3 Mathematics, Measuring, and Meaning Making

It is often taken for granted that mathematics is integrated into scientific study; however, making the connection explicit becomes most important when students analyze data. In Chapter 4, students in Ms. Kane's class analyzed data indicating freshwater salinity levels in streams in urban, forested, and suburban areas of Baltimore County, Maryland. Ms. Kane knew that in order for the students to understand the concept of "milligrams per liter," the units of the data, the students would need to make salt solutions using digital scales, beakers, and graduated cylinders. The impact of the salt on freshwater streams could then be examined. In the following story, a fourth-grade class is interested in helping their school reduce cafeteria waste. At this Vermont elementary school, students come from long distances, and lunch is always served in school. These students needed to take measurements to make their point! This is another example of using mathematical and computational thinking (SEP 5) to help with an environmental problem.

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SCIENCE STORY

How Much Milk Are We Wasting?

In Ms. Rhodes's fourth-grade Vermont classroom, a unit on recycling and conservation prompts a class to consider the amount of milk wasted in their school cafeteria during lunchtimes. The students' problem is twofold: (1) how to calculate the volume of milk wasted, and (2) how to enlist all the students in the school to help curb this waste.

The class obtains the help of the school custodian, who brings discarded, but not empty, milk containers to the classroom each day for a week. Working in groups of four and using 1,000-milliliter graduated cylinders, the students measure the amount of milk wasted on each day. They wear rubber gloves and handle the milk containers carefully. They count the number of containers that are thrown away each day and then pour the contents of each container into a graduated cylinder. They construct a huge bar graph titled "Milk Waste" outside their classroom, labeling the axes with "day of the week" and "liters of milk wasted." Under the graph, they pose the question, "What can YOU do about the amount of milk we waste in our school?" For four weeks, Ms. Rhodes and her 27 fourth graders post a new graph each week, displaying the volumes of milk that were discarded on each day of the preceding week.

The students also visit other classrooms, talk about the problem, and gather suggestions. By the end of the school term, as a result of their efforts, there is a 70 percent decrease in the milk wasted!

As this story demonstrates, environmental concerns become especially meaningful when students relate it to their own habits.

The Teaching Ideas behind This Story

- Ms. Rhodes is concerned with the students' measuring skills. She is also interested in raising their awareness of waste in their environment. By using the amount of lunchtime milk that is discarded as a pressing, very local, issue, she engages the students' interests as well as their measuring and observation skills.
- Enlisting the help of the school custodian enriches the experience and enables the class to see this staff member as part of a real investigation.
- By posing the question to the students, "How much milk do you think we discard every day?" Ms. Rhodes begins an open-ended investigation. The students have to design an authentic procedure that ensures a fair level of accuracy.
- The overarching idea of this milk-waste activity is how our individual actions affect the amount of waste in the environment and the quality of our local environment.
- The science and technology ideas behind the activity are integrated with mathematics and design as students construct their bar graphs for all to see. This a STEM education experience.

The Science Ideas behind This Story

- Measuring liquid volume is a fundamental and frequently used laboratory task.
- A *graduated cylinder* is a cylindrical glass (or plastic) tube sealed at one end with a calibrated scale etched (or marked) on the outside wall. Graduated cylinders come in a range of sizes (volume capacities), and they are used in much the same way as a measuring cup. Volume is measured by adding liquid to the cylinder and comparing the liquid level to the graduated scale.
- The liquid surface is curved (U-shaped) rather than horizontal. The curved surface is called the **meniscus**. As a general rule, the bottom of the meniscus is taken as the liquid level in the cylinder (and in any other volume-measuring device).

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- More than 55 million students attend school in the United States, and the waste generated by schools, universities, and colleges is staggering. Elementary school lunchrooms discard more than four million dollars' worth of food daily. New USDA food standards are increasing the amount of food waste. In some localities schools recycle these nutritious foods to homeless shelters (Regan, 2014).

Connections to the Next Generation Science Standards

- **NGSS DCIs:**
  - **3-LS4-4: Biodiversity and Humans:** Populations live in a variety of habitats, and change in those habitats affects the organisms living there.
  - **3-LS4-4: Ecosystem Dynamics, Functioning, and Resilience:** When the environment changes in ways that affect a place's physical characteristics, temperature, or availability of resources, some organisms survive and reproduce, others move to new locations, yet others move into the transformed environment, and some die.
- **NGSS SEPs:** Students *planned and carried out their investigations; analyzed their data; used mathematical and computational thinking; engaged in argument from evidence;* and *obtained, evaluated, and communicated information.*
- **NGSS CCs:** Students examined *patterns* as they collected data; *cause and effects* of milk waste; and *scale, proportion, and quantity.*

Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- One idea for conserving food waste at lunchtime is to seek out a food donation program for your school instead of discarding unused cafeteria food.
- You may want to explore other types of liquid waste, most notably water. Only 3 percent of the water on earth is freshwater; the rest is salt water. Fresh drinking water supplies are becoming increasingly scarce. More than 650 million people do not have access to clean water.
- Investigate the idea of waste-free lunches. Can we eliminate plastic bags, plastic utensils, disposable containers, and brown paper bags?

11-4 Science and Engineering Design in a Second-Grade Class

meniscus
Refers to the curve at the upper surface of a liquid in a cylindrical container, such as a graduated cylinder. The bottom of the curve in a concave meniscus (liquid surface caves downward) is where the liquid volume measurement is taken.

As we have seen, the Next Generation Science Standards include science and engineering practices (SEPs) that encourage teachers to engage students, not only in planning investigations, but also in asking questions, defining problems, and designing solutions. While science begins with questions, engineering most often begins with defining a problem to solve (NGSS Lead States, 2013). We are in a second-grade class of gifted students in a Midwestern suburb, and Ms. O'Connor is implementing a science unit on magnets. What are the possibilities in second grade for the students' understanding of magnets? In the story that follows, students design a magnetic levitation (maglev) "vehicle" that "glides" down a maglev track. Wooden blocks have Velcro strips that hold the magnets on the bottom of the vehicles. The magnets are just the right size to be secured to the Velcro strips on the bottom of each wooden block (car). They are small rectangular magnets with Velcro on one side and with either the N or S pole of the magnet on the other side. The challenge for these students in

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the spring of their second grade is to figure out how to place the magnets on the bottom of the wooden block so that their "car" levitates down a seven-foot track. This track was made by students at the high school and consists of a long strip of wood onto which two parallel magnetic strips of metal are secured.

SCIENCE STORY

An Exploration of Magnets and Forces

We visited Ms. O'Connor's class two days after the "Magnet Circus." This was a science circus designed to have stations that only dealt with different properties of magnets. The magnets at each station were of different sizes and shapes; some were bar magnets, some looked like horseshoes where the poles at the end are very close to each other, and others were disc magnets that have their opposing poles on opposite sides. The small rectangular magnets also have their north and south poles on either *side* of the magnet, not on the ends, as in a bar magnet. Each station had a different magnet activity, and Ms. O'Connor's goal was to have students understand the following ideas:

- A magnet is an object that contains metal and attracts some other metals.
- The poles of a rectangular magnet are located on each end.
- Attraction is when an unseen force pulls two objects toward each other.
- Repulsion is when an unseen force pushes two objects away from each other.
- The poles of a magnet are called north and south, and opposite poles attract each other but similar poles (north and north and south and south) push away from (repel) each other.

Ms. O'Connor prepared for this unit by gathering many materials: magnets of different sizes and shapes; aluminum foil, nails, pennies, nickels, dimes, silverware, jewelry, screws, plastic paper clips, metal paper clips, rubber bands, and more. The materials for the engineering design part of the unit included two seven-foot magnetic strip (maglev) tracks and a kit of materials that included wooden blocks (cars) with four Velcro pieces glued in the corners on one side of the block and many small magnets labeled N or S with Velcro glued on the other side.

At each station, the students experimented with magnetism, learning what materials were attracted to a magnet, how to make other materials magnetic, how magnetism can travel through materials, and how magnets can be attracted to and repel one another. They learned about the north and south poles of the magnet and that opposite poles attract and similar poles repel.

After the "Magnet Circus" stations, on the very next day, Ms. O'Connor did the following demonstration: She taped a bar magnet to the edge of a table, allowing the greater part of it to hang over the side. She then tied a string to the bottom of the table's leg, and to the open end of the string she tied a paper clip. With the string taut and the paper clip centimeters away from the magnet, the attraction was so great that the paper clip appeared suspended in air (Photo 11.1). The students stared in amazement and were quiet for a few seconds. Many of the children tried and tried on their own to duplicate the paper clip experiment, and some were successful. Others were exploring how long the string had to be to make this happen. The unseen force was clearly traveling a few centimeters between the paper clip and the magnet attracting it. The magnet was holding the paper clip up and the string was pulling the paper clip down. The students continued to repeat the demonstration whenever they found a free moment. This was Ms. O'Connor's introduction to their design challenge.

The next day, the students researched magnetic levitation trains that could be found in China, Germany, and Japan. On the Internet, they viewed the way these trains seem to hover over the magnetic tracks. The students used the How Stuff Works website (http://www.howstuffworks.com/maglev-train.htm) to locate information about how the trains levitate above the tracks. Ms. O'Connor then introduced the students

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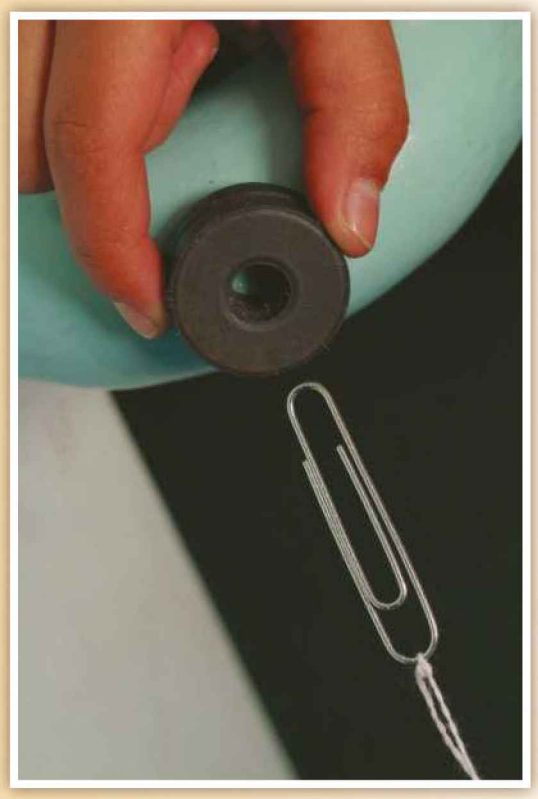
PHOTO 11.1 The paper clip is a few centimeters away from the magnet and yet it is still attracted to it.



Michael Newman/PhotoEdit

to their wooden block "car" with the Velcro patches on the bottom and the magnets that attach to those sites. The children begin to understand that their challenge is to design the placement of the magnets on a wooden block ("car") so that their car would "float" or levitate down the two classroom maglev tracks. By this time, the students had completed their magnet activities and they were ready to apply what they knew about magnets attracting and repelling each other to design their "levitating car."

On the day that the students were to test their cars, the two maglev tracks were set up in the back of the classroom (Figure 11.1). The students had to place their magnets on the bottom of their cars in such a way that their cars would glide down the track. The goal was for the students to understand the ways in which to set up the magnetic repulsion in order for the cars to go swiftly down the track. The students drew plans for how their magnets would attach and indicated which poles were facing the track—N or S. They worked with a partner and drew their plans in their design portfolios.

Ms. O'Connor asked probing questions as the students stood at eye level at the beginning of the track and made observations about whether there was magnetic attraction or repulsion. She asked, "What do you think went wrong? Let's look at the pattern of your magnets on the bottom of the car—what's

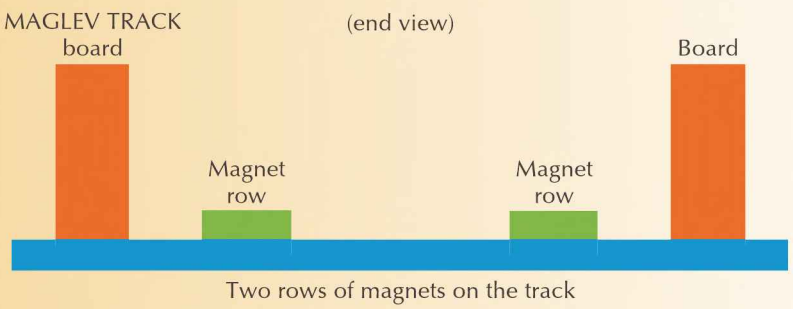


FIGURE 11.1 A side view of a classroom maglev track

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happening?" The students were completely engaged in redesigning the placement of their magnets. Ms. O'Connor offered no judgments, only observations, and empathized as the students had to rethink their designs.

By plodding along, each group was able to learn the polarity of each of the magnetic strips on the track. In that way, they could align the poles on their Velcro magnets so that they would be repelled by the tracks. Noticing that each side of the track was a different pole, they lined up the magnets with the north pole side facing up on one side of the bottom of their car and the south pole side of the magnets facing up on the other side. They said things like, "The poles were the same, so the car kept levitating," or "We need to line up the south-side magnets on the same side as the south pole track." These second graders were adept at explaining how north and south poles attract each other, and they really understood the concept when the car "worked." Ms. O'Connor asked the students to look at what worked and what was not working each time they came up to send their car down the track. Ms. O'Connor asked, "What did you learn?" Students were engaged in conversation and discussion with the teacher and their peers as they experienced the effects of like poles repelling.

The Teaching Ideas behind This Story

- Notice how Ms. O'Connor scaffolds student learning by engaging them in a "Magnet Circus."
- This multistation activity asks students to perform a magnet activity at each stop. (See the science circus in Chapter 3.)
- The students get to experience magnets of different sizes and strengths.
- Ms. O'Connor allows students a wide range of free experimentation, even allowing them to try to repeat her paper clip demonstration. This encourages student responsibility and autonomy.
- Asking students to design a model maglev "car" connects science and engineering practices to designing a solution.
- By using their understanding of magnetic attraction and repulsion in designing the "car," students gain practice *applying* the concept to a real-life experience.

The Science Ideas behind This Story

- Human-made magnets are made from iron, steel, cobalt, and nickel and are named for their shapes: bar magnets, rod magnets, horseshoe magnets, disc magnets, and U-shaped magnets.
- The force of a magnet is strongest at its ends, which are called the poles of the magnet. For disc magnets, the poles are on either side of the magnet.
- When the poles of two magnets are brought near each other, like poles repel each other and opposite poles attract. That is, two north poles tend to push each other away. So do two south poles. But a north and a south pole tend to pull each other closer.
- The magnetic strips on the maglev tracks were south-pole facing and north-pole facing; hence the magnets on each side of the bottom of the wooden block needed to be south-pole facing and north-pole facing, respectively. This way like poles repel each other and the "car" levitates down the track.

Connections to the Next Generation Science Standards

- **NGSS DCI: 3-PS2-3: Types of Interactions:** Electric and magnetic forces between a pair of objects do not require that the objects be in contact. The sizes of the forces in each situation depend on the properties of the objects and their distances apart and, for forces between two magnets, on their orientation relative to each other.
- **NGSS SEPs:** Students *planned and carried out investigations; designed solutions; argued from evidence; developed and used models;* and *obtained, evaluated, and communicated information.*
- **NGSS CCs:** Students observed *patterns* and studied *cause and effect* mechanisms.

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Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- In what ways were the students acting like scientists? In what ways were they acting like engineers?
- Why was it important for them to draw their plans before trying it out on the track?
- Why do you think the students kept redesigning their magnet placements until they were successful without giving in to frustration?
- Why didn't Ms. O'Connor just tell the students where to place the magnets?

As you can see from this story, just learning what materials were attracted to magnets and how magnets attracted each other was not sufficient for this second-grade class. It was much clearer to the students that magnetic forces can be very powerful when their teacher applied the principle to design and engineering. Many middle schools classes use maglev tracks for engineering lessons, and the students create more elaborate designs.

In the following story we examine how science becomes a tool to solve a problem of authentication in the world of art history. This experience relates to a movement connected to STEM education called "STEAM," where the "A" stands for "Art." When this type of integration is possible, it enhances students' understanding of how useful STEM subjects are in the art world and how the use of artistic depictions can enhance STEM experiences. In the following story, middle school students can learn how STEM subjects helped art historians reach a conclusion about a piece of artwork. Look for how the story depicts the nature of discovery and the importance of authentic evidence. As you read the story, look for what counts as evidence. This is suitable for middle school grades and above. This is one of thousands of stories of the marriage between science and art.

11-5 Making the Science and Art History Connection

If you have ever visited an art museum, then you know that many of the paintings are very old and beautifully framed. What if *you* found a very old drawing or painting in an attic and wondered if it too belonged in an art museum? What would you do? In the next story, we examine a case of science intersecting with the art world to solve a mystery. This is a different kind of science story from the others in this book. It is a story of discovery that you can *use* to teach science.

SCIENCE STORY

Is She or Is She Not a Leonardo?

"La Bella Principessa" is a small portrait in profile of a young woman about fourteen years old, on sheepskin (Photo 11.2). It is a drawing, not a painting. In August 2008, an article appeared in the *New York Times* that cited the possibility of this portrait being an authentic work of Leonardo da Vinci. The 13-by-9.4-inch

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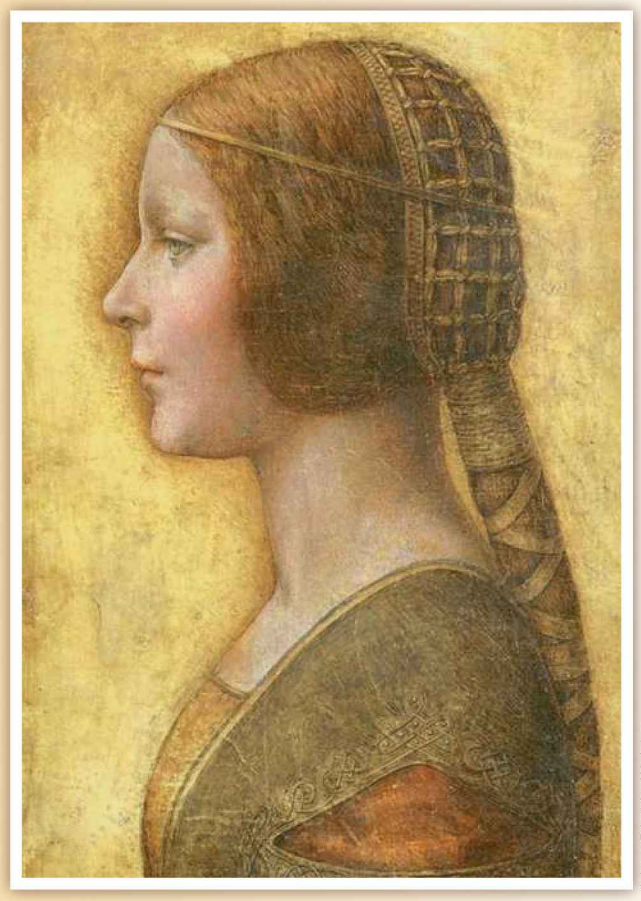

Science Television Workshop

PHOTO 11.2 "La Bella Principessa," first named "Profile of a Young Fiancée," believed to be a work of Leonardo da Vinci created around the end of the fifteenth century.

work—which is thought to be a betrothal portrait—was named "Marriage Portrait of a Young Woman" or "Portrait of a Young Fiancée," and it had already been sold by an auction house in New York City and then sold again to another private collector. The artist was presumed to be unknown, so you can imagine the excitement over the possibility that this was an original work of a great artist. The auction house that originally sold it said they "cannot comment on this particular work until it has been the subject of comprehensive and conclusive academic and scientific analysis" (Povoledo, 2008). *What do you suppose that means?*

The events that followed resulted in the collection of a large amount of data. In order to answer the question, "Is she or isn't she?" art historians, technologists, and scientists had to work together to develop their argument with *authentic* data. My friend, Jo Ann Caplin, an Emmy award–winning television producer and an art and science historian, told me the story of its authentication.

Finding a portrait done by Leonardo da Vinci is a major event, something that might happen once every 100 years. And this one is indeed different. Leonardo did many beautiful drawings and sketches of nature and anatomy and machines, all found in his notebooks, but this one was a formal portrait done on sheepskin colored with dyes. We know of no other portraits by Leonardo done on sheepskin. Jo Ann decided to film the story of the authentication of this work. She traveled to Europe, where she and Martin Kemp, the Leonardo scholar at Oxford in England (who has since written a book about this process), visited Lumière Technology in Paris, a company that has developed extraordinary technology for analyzing works of art. Optical engineer Pascal Cotte is the inventor of the first thirteen-band multispectral camera, which allows for digitizing art with up to 420 million pixels. That means that one can blow up the images for careful study without losing detail. There are two major paintings of Leonardo's already scanned by Lumiére Technology. And now, there appears a portrait of a young woman, possibly done by the master hand of Leonardo. This one, however, is not a painting; it is a drawing done on sheepskin with chalks and ink and dyes.

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What Is This Portrait? Examining the Scans

> *Science meets art in a scholarly dance of authentication.*
> —Jo Ann Caplin (2011)

The portrait was scanned in at about 4,000 pixels per square millimeter, so we could examine her in great detail. At the time that Jo Ann viewed her, she was thought of as a "match.com of the Renaissance," a portrait done to show a potential fiancé how beautiful his betrothed was. Having portraits of possible engagements before marriage was a common practice during the Renaissance. But as the researchers looked more closely at the scans, another possibility became apparent. On the left side of the portrait, which now was entirely mounted on an old oak board, was an uneven edge, cut not by scissors but by a knife. They could see where the knife slipped. They could also see that there were three holes on the left side of the sheepskin, suggesting that this portrait might have been the cover of a hand-made bound booklet. Martin Kemp noted that it could have been the frontispiece for a manuscript written in honor of this young woman. That would explain the sheepskin.

The scans on the skin tones revealed white lead, red, and green pigments, but not yellow. Doing skin tones on a yellowish sheepskin, or vellum, had to be different than painting on a white canvas. "Ah," said Kemp, "so that explains it; he used white, red dye and green and the yellow was from the sheepskin itself." Then, as they examined the eye, they realized that the amber color of the eye was just the color of the sheepskin—that it wasn't colored at all. Also, as they examined the eye in extreme close up, the tiny wisps of eyelashes were apparent—tiny, precise, delicate lines. They learned through the scans that the design on the dress and the hairs were also drawn with chalk and translucent brown ink. The coloring of the skin, hair, and dress, however, were done with organic dyes.

Then they examined more of the handiwork on the portrait. The left-handed "hatching"—tiny parallel lines that Leonardo used for shading, which are uniquely Leonardo's—was more evidence that this might have been done by the hand of the master himself, rather than by one of his followers. In some works of the followers, right-handed hatching can clearly be seen, going in the opposite direction from left-handed hatching.

The young woman's dress is that of an upper-class Milanese lady of the late fifteenth century. The colors of the dress are green, red, and white, favored colors of the Duke of Milan at the time. The elaborate knot design detail on the dress is typical of the design details that Leonardo was fond of.

A tiny slice of the vellum of the portrait had been sent to the physics department at the University of Zurich, Institute for Particle Physics, for **carbon-14 dating**. The result: The dating showed that the vellum was 100 percent somewhere between 1449 and 1656. Leonardo lived between 1452 and 1519. Hence, by the time Jo Ann Caplin and Martin Kemp went to Switzerland where the portrait itself was kept, they were very excited. The portrait was in an anonymous warehouse in a large wooden box, well packed for shipping. With everyone wearing white gloves, "Profile of a Young Fiancée" was placed into Martin Kemp's hands (Photo 11.3). Kemp pulled out a jeweler's glass and began to examine her closely. He quietly examined the portrait for what seemed like hours. Finally he put her down. "My first impression is that it's very pretty. I have to say seeing the original, it's full of signs of Leonardo. It's just fascinating looking at something having seen all the technical evidence—it very much affects how you look at it, which was the idea of going to Paris first, so I had guided looking."

Kemp went on, "That being said, it is in good condition for something of its age. This woman is 500 years old. If you or I looked this good after 500 years we'd be doing a good job." He confirmed that they should consider her condition normal for something 500 years old. Martin Kemp went on, "It is not a forgery—it conceivably could have been a close copy of a follower, but looking at all the technical evidence, looking at the way it is left-handed in the hatching—not a right-handed person doing left-handed hatching and you can see that very, very clearly in the big scans—so it's not by a follower—the technical evidence says it is not a forgery. . . . So ultimately however hard we work with scientific analysis, however hard I work on patronage and intellectual context—there is that element where you just have to say, 'that is just fantastic and it's the real thing.' And having looked at it closely I am prepared to say that I think it's fantastic and it's the real thing."

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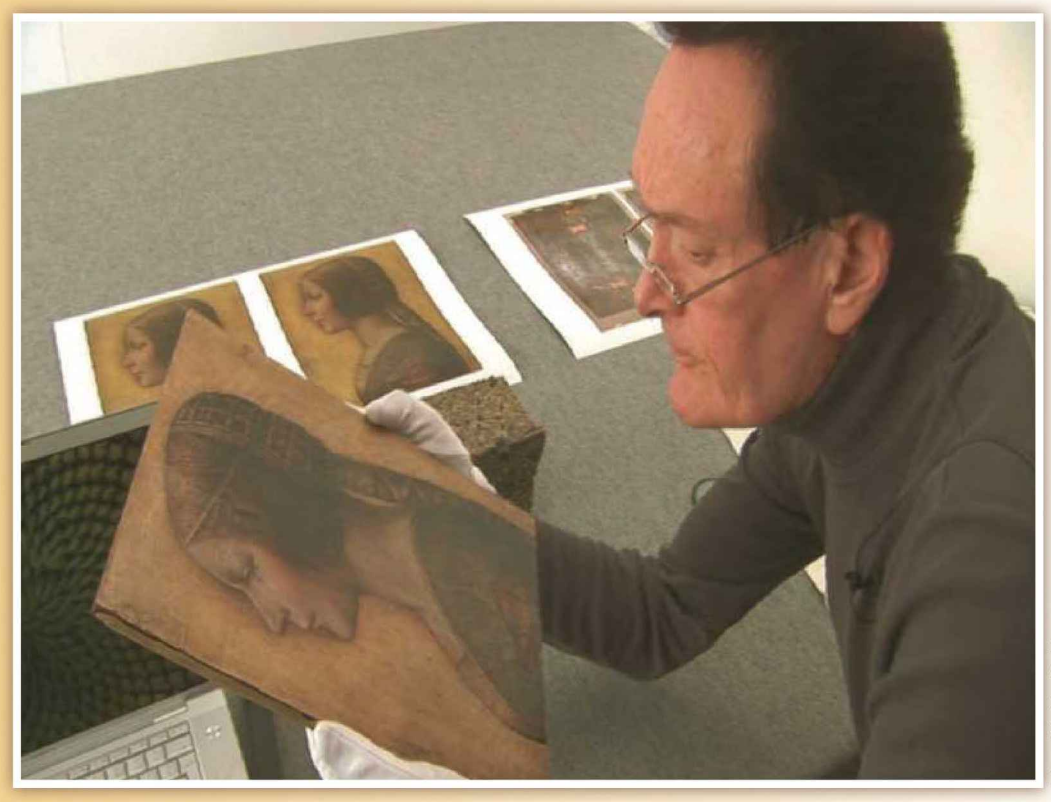

PHOTO 11.3 Martin Kemp examining the portrait.

When researchers first saw the portrait in 2008, there was the thought that she was a sort of "matchmaker" portrait from the Renaissance. It was common practice in the Renaissance to have the best court artists do a sitting with a betrothed, so noblemen, princes, and kings might agree—or not agree—to the marriage. With that thought, the painting was named "Profile of a Young Fiancée." Kemp's research made it possible that there was a different use for the work, as the cover of a manuscript of poems about her. It was apparent that she was a beautiful young woman wearing a dress and having a hairstyle of the upper class of Milan in the late fifteenth century, so he renamed her "La Bella Milanese." There were complaints that the name made her sound like a veal chop. So with more research about whom she might have been, Martin Kemp gave her the name she now has, "La Bella Principessa."

The first showing of "La Bella Principessa" was in March 2010, at a commercial exhibit of the Renaissance masters Leonardo da Vinci, Michelangelo, and Raphael in Gotenberg, Sweden, called "And There Was Light." The exhibit was put together by Director of the Vatican Museums Francesco Buranelli and Alessandro Vezzosi, head of the Leonardo Museum in Vinci.

Source: Adapted from Caplin, Jo Ann. "The Da Vinci Question." *Chemical Heritage* 29, no. 1 (2011): 32–36.

The Teaching Ideas behind This Story

- The nature of evidence is the grounding of all scientific study.
- Revealing this story and showing an account of it engages students in a discussion of what counts as evidence.
- The role of technology in providing evidence for claims of authenticity is unmatched by any other time in our history. The puzzle of "why on vellum?" was solved by the digital scan of the portrait and how the holes would indicate a frontispiece of a bound volume.

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- Explore with the students how authentication could not proceed without the scientific dating of the vellum. Carbon-14 dating is known to be reliable (see The Science Ideas behind This Story below).
- Science students need to acknowledge the role of art historians as well as historians of the era. Their input is vital in amassing evidence for the period of time of the portrait's creation.
- Remind students that isolated pieces of data rarely provide conclusive evidence for an authentic finding. It is the collaborative evidence that renders a theory sound.
- Ask your students to decide on whether the evidence is conclusive. How long does a theory have to exist before it is said to have endured the test of time?

The Science Ideas behind This Story

- Vellum is mammal skin, in this case sheepskin. It is smooth and durable and was manufactured to be used for writing on after going through a complex process of cleaning, stretching and scraping, and wetting and drying repeatedly.
- Carbon-14 is a naturally occurring form of carbon (an isotope). Plants take in carbon dioxide as part of the process of photosynthesis. Animals eat the plants, and some of the carbon-14 becomes part of the animal. What makes carbon-14 useful for dating a piece of organic matter, like the vellum in this story, is that it also spontaneously decays—it is radioactive. It decays at a fixed rate. Therefore, calculating the amount of carbon-14 in a sample and comparing it to the amount of carbon-14 expected in the atmosphere allows the sample to be dated. It is as old as the number of years it takes for the expected carbon-14 amount to decay to the amount found in the sample.
- Making observations in science is enhanced by technology. The multispectral camera in this story enhances observations of works of art by digitizing and allowing a greatly magnified image without distortion.
- Communities of scientists arrive at new theories based on collective evidence and shared observations and inferences. Often investigations get repeated. Martin Kemp's analysis may be repeated by art historians and scientists several times before "La Bella Principessa" becomes fully accepted as a Leonardo.

Connections to the Next Generation Science Standards

- **NGSS DCIs:**
  - **MS-PS1-1: Structure and Properties of Matter:** Substances are made from different types of atoms.
  - **HS-PS1-1: Structure and Properties of Matter:** Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
  - **HS-PS1-8: Nuclear Processes:** Nuclear processes, including radioactive decay of unstable nuclei, involve the release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.
  - **HS-PS4-5: Information Technologies and Instrumentation:** Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world and in scientific research (medical imaging, scanners).
- **NGSS SEPs:** Caplin and Kemp engaged in *asking questions and defining problems*; *developing and using models*; *analyzing and interpreting data*; *using mathematics and computational thinking*; *constructing explanations and designing solutions*; *engaging in argument from evidence*; and *obtaining, evaluating, and communicating information*.
- **NGSS CCs:** Embedded in this exploration are the practices associated with *patterns*; *cause and effect*; *structure and function*; *stability and change*; and *scale, proportion, and quantity*.

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Exploring Further

To implement this activity in your own classroom, you may want to consider the answers to the following questions:

- How could you model a magnified image that has many pixels?
- What role does carbon-14 dating play in this authentication?
- How will you address the moment when Martin Kemp appears to just go for it and says "I think it's fantastic and it's the real thing." What is the role of personal certainty and intuition in science?

11-6 STEM Education and More

carbon-14 dating
The process of determining the amount of the naturally occurring radioactive isotope, carbon-14, found in old carbon-bearing materials. When compared with the amount of carbon-14 naturally occurring in the atmosphere, the approximate age of the material is determined. Based on fixed rates of radioactive decay. Accurate to 60,000 years.

These stories illustrate that all ways of knowing the world contribute to our fuller understanding of how things work and of how different areas of study connect with each other. Just as engineering design helps us to apply science concepts, mathematics helps us to demonstrate and promote conservation in a Vermont elementary school. Science can be explained through poetry just as science can better help us to understand works of art. Recognizing the significance of carbon-14 dating as a reason to pursue further authentication is what kept Caplin and Kemp going. Later, in Chapter 13, when we examine assessment strategies, look for the ways teachers use dance and poetry as understanding performances. Sometimes disciplinary boundaries get fuzzy and exciting multidisciplinary connections are made.

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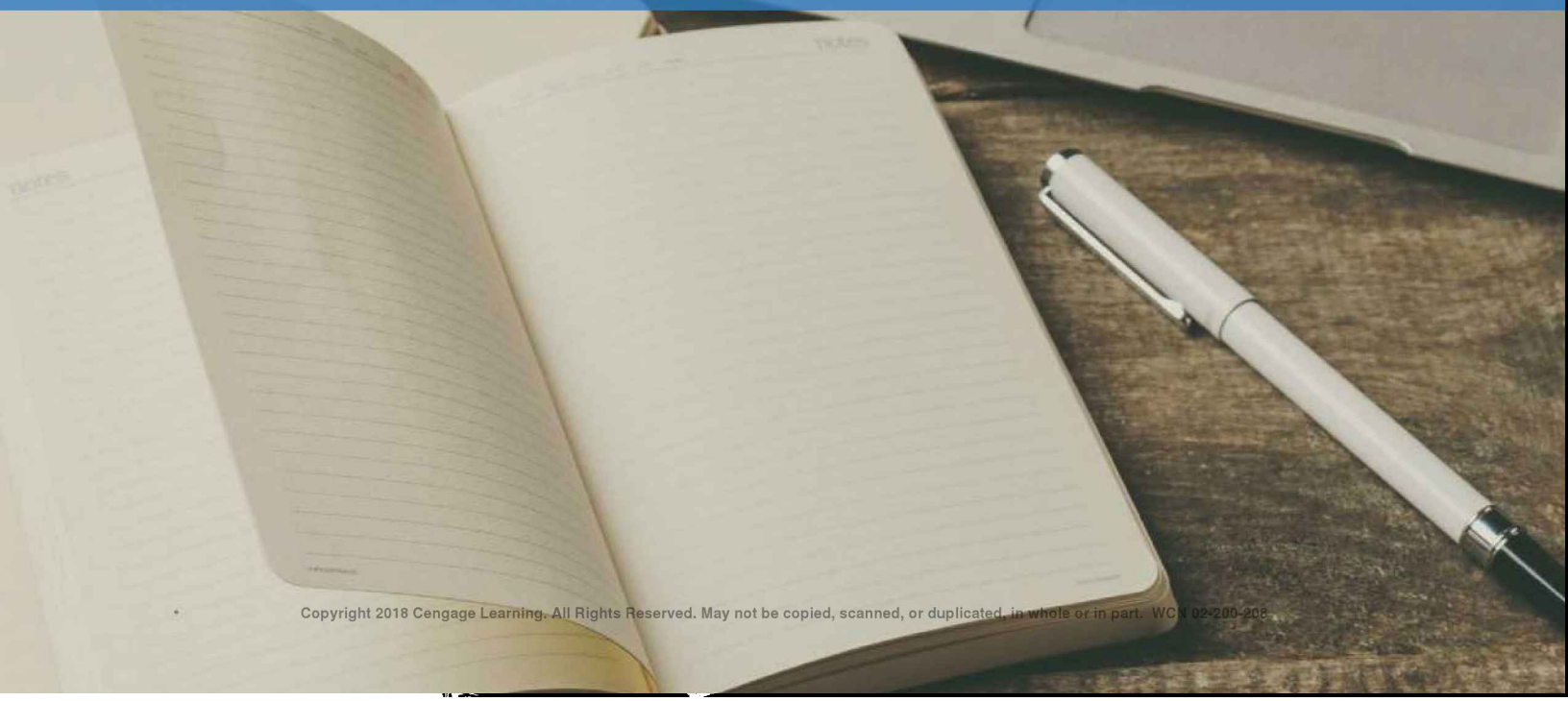
CHAPTER 12

Planning for Science: Instructional Strategies



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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 12-1 Discuss how to encourage underrepresented groups in science to embrace scientific exploration.
- 12-2 Examine the strategies unique to exploring science with English Language Learners (ELLs).
- 12-3 Analyze how an activity can become a lesson.
- 12-4 Examine and critique a sample science lesson plan.
- 12-5 Explain the role of lesson planning for teaching science.
- 12-6 Provide a rationale for departing from the lesson plan.
- 12-7 Discuss the characteristics of a good question.
- 12-8 Examine why group learning has benefits for individuals.
- 12-9 Examine the best ways to form cooperative learning groups.
- 12-10 Understand what is meant by inclusive science education.
- 12-11 Appreciate how technology can support the success of students with disabilities.
- 12-12 Analyze how to critique your science lesson.

Reflection

To Think About:

- What is the difference between a science activity and a science lesson?
- Do you prefer to learn independently or in small groups?
- How do you plan for the unexpected?
- How can you set up your science lessons if you have only forty minutes in a period?
- What is your own personal style when it comes to planning?

A friend of mine used to say as each school year began, "Remember, Janice, teachers can never be overprepared." As I gained experience in teaching, I discovered what he meant.

Being prepared means, first and foremost, having done your planning. To develop a plan that helps to guide your instructional practice, you need to give serious consideration to the learning experiences you want to provide. Then you need to organize and structure those experiences in ways that make sense to you and to your students. When you come to school prepared, the students recognize it, and they develop an image of you as hardworking and caring. This image helps you create a sense of community in the classroom. It is also a model to your students of what it looks like to work hard and arrive prepared for class.

In an earlier chapter of this book, I mentioned that we teach "who we are." That applies to planning as well as to your performance in class. One size does not fit all. In this chapter you will find suggestions for planning for school science, but I expect that you will adapt these ideas to your own personal style. In Chapter 10 we explored planning for an entire science unit or a curriculum for a grade. In this chapter we examine instructional strategies for the

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lesson. We begin by visiting the ways in which your students differ from each other. For example, they may all be fifth graders, but their cultures, socioeconomic status, religions, and native languages may be very different.

12-1 Encouraging Underrepresented Students in Science

Various researchers have investigated the reasons why science has often alienated students, especially females and members of minority groups. Studies have found that a major culprit is the absence of personal connections between science and students' everyday lives. For example, minorities and females often have a negative perception of the usefulness of science in "real life," and this attitude contributes to their lack of participation in science activities (Burger et al., 2007; Koch et al., 2014). Conversely, by relating science to our students' daily lives, we can create school science experiences that will invite their participation. We also know that what works for students who feel disenfranchised by science amounts to simply good science teaching. Hence, making connections by showing the ways that science enters our lives as a means of understanding the natural world awakens the interests of *all* students.

Remember that students come to school with a set of biases and beliefs about their world that are constructed from the social, cultural, and gendered contexts in which they live. These beliefs strongly influence students' tacitly held attitudes toward science and scientists. Part of your work as a science educator is to learn about your students' views of science and then use that knowledge to help them modify and enlarge their views.

As we saw in Chapter 1, science is frequently perceived as a domain for white males, from which women and all people of color are excluded. In addition, the mass media often portray science as a relatively impersonal field. For example, many television documentaries show the results of scientific work—the content of science—rather than the process of science or its human side. Science then seems a dry collection of facts and principles. This absence of the human face helps to create in students a deep and abiding lack of interest in scientific study. Hence, it is imperative that teachers use science experiences to make connections with their students' daily, lived experiences.

As we have seen in the stories in this book, there are many ways to integrate scientific study of the natural environment into the daily life of your classroom. Yet, even when learning about subjects critical to the world they live in—the water they drink, the air they breathe— all students can be put off by a detached, fact-based approach. Hence, a deep understanding of who your students are, what their lives are like, and where and how they live, combined with your own passion for and understanding of the concepts, will help you to plan effectively to engage all students. A first step in planning is (1) understanding the science content and (2) knowing how it fits with the instructional strategies or pedagogy. This refers to the term we introduced earlier, *pedagogical content knowledge*: know the content, know the pedagogy, and combine them! A way to start is to consider some of the following:

1. An activity is important but is not the whole lesson.
2. Students need to ask questions and come up with their own ideas.
3. You need to make your approach visible to the students so they feel a part of the planning.

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First, we explore additional planning that is required if we are teaching students with limited English language skills. Students whose native language is not English often struggle with science concepts even though they are very capable. This is because the language of science can often be confusing to students who have not mastered the English language.

12-2 Teaching Science to English Language Learners (ELLs)

As we explore some suggestions for planning the science lesson, keep in mind that, as revealed by the science stories you read, there is a lot going on in a science lesson. For students who are not native English speakers, the instructions and vocabulary may be particularly challenging. The following model of science instruction for ELLs was developed by two professors at Texas Christian University in Fort Worth, Texas (Weinburgh & Silva, 2012). They reasoned that the 5E model of science instruction could be confusing for students whose English language skills were emerging, and they developed a 5R model of instruction to accompany the science lesson and build understanding and new language.

Inquiry-based lessons that model science as practice may appear to an outsider as unstructured and chaotic when, in fact, as the chapter explains, the best inquiry-based lessons are well thought out by the teacher and involve the teacher's orchestration of many interwoven parts. For ELLs, the 5R Instructional Model can be integrated into the planning process as a teacher decides what scientific language is important in developing and expressing a concept and how that language can be introduced and strengthened during a lesson.

The five components of the 5R Instructional Model are *Reveal*, *Replace*, *Repeat*, *Reposition*, and *Reload* (see Table 12.1). Notice how, for ELLs, the teacher needs to introduce the English language terms that the students will encounter as the lesson proceeds. This is not a replacement of the traditional 5E model of planning a science lesson. This is in addition to the model specifically for students who are not native English speakers.

TABLE 12.1 5R instructional model

	Description	Level	Example	Timing
Reveal	The teacher provides or introduces students to the vocabulary (or word labels) for new concepts that are introduced in the lesson. Based on the students' background knowledge, the teacher can anticipate which words will need to be revealed and during the planning phase identifies places in the lesson where the language should be introduced.	Word	Giving the name of parts of an atom (electrons, neutrons, protons) or a new process (distillation)	Anytime in unit
Replace	The teacher uses the language that emerges within student talk from the context of the lesson to substitute informal with more formal words. The students already have an everyday word for the object or concept.	Word	If the students say, "The metal moves the heat," the teacher can suggest they use "conducts" instead. The teacher would say, "In science when we talk about heat, we would say the metal 'conducts' instead of 'moves.'"	Anytime in unit

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Repeat	The teacher says the word multiple times and in different forms. This can be different forms of the same word or different sentence structures and different contexts. The teacher also encourages the student to repeat the word.	Word	To stress the word "model," the teacher can say, "I see the model of the earth." "We will use a model for our experiment and I will model how to use your safety goggles." Other examples are the various uses of *erode*—erode, erosive, erosion or divide, division, dividend.	Anytime in unit
Reposition	The teacher, knowing the discourse of science, restructures sentences to have the linguistic features associated with the discipline.	Sentence	If the students say, "It takes up more space," the teacher says back, "The cylinder has more volume."	Anytime in unit
Reload	The teacher uses the strategies of language instruction to visit words a second time.	Word and sentence	The teacher can use Word Walls or other strategies to remind the students of how to pronounce words and how they are used in a sentence.	After introduction

As we examine the components of planning the lesson, think about how the 5R model can be integrated into the science experience.

12-3 An Activity Is Not a Lesson

A major part of planning is setting up the investigation that your students will pursue. As earlier chapters have demonstrated, it is only by providing students with meaningful science experiences—such as experimenting with liquids, exploring atomic structure, or investigating earthworms—that we can lead them toward critical exploration of their world. Planning, therefore, involves acquiring and organizing the appropriate materials and deciding how you will engage the class in the activity. The investigation or activity that you select should be aligned with the NGSS DCIs. Look at the performance expectations for the DCIs as you prepare plan for an activity. For example, for the second grade DCI 2-PS1-1, "Matter can be described and classified by observable properties," the performance expectations state, "Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties" (NGSS Lead States, 2013, p. 16).

Planning for this alignment to the standards and designing an appropriate activity or investigation are just the beginning of the planning process. Although students may have a lot of fun experimenting with the materials you give them, *an activity is not a lesson.* You need to know what science concepts you expect your students to develop. Most important, it is not just the activity but the process of reflection and dialog that can lead to the construction of new ideas. Your responsibility is to facilitate the thought experience as well as the active experience. This involves helping to scaffold the students' ideas. Not every time you do science with your students may include a specific science activity. The students may have completed the investigation in the science time allotted; however, the active reflection part may be relegated to the next day. The science **lesson** includes both the investigation *and* the process of reflection and discussion. In the sections that follow, we will begin with the lesson plan itself and then address the role of questioning, the use of cooperative learning groups, ways to make sure all students are fully included, and some guidelines for reflecting on your teaching experience.

lesson
In science instruction, the process of engaging students in a meaningful science experience and in reflections on the experience.

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One more introductory point: Careful planning also includes the plan to drop the plan! This may sound like a contradiction, but when students are engaged in genuine inquiry, one question often leads to another. Your students' spontaneous curiosity will give you excellent opportunities to change your original plan and mediate their experience on *their own terms.* Remember to keep in mind the important science ideas that can emerge from a successful science experience and remember what happened when Ms. Drescher extended the activity and lesson and introduced the construction of liquid science toys in Chapter 7.

12-4 Planning the Lesson

lesson plan
A document describing a teacher's plans for a particular lesson, including the ideas presented in the lesson, the activities that students will engage in, and the ways in which the teacher will help students reflect on their experiences.

Let's imagine that you are planning a new science lesson for your class. What type of **lesson plan**—that is, a document that describes your plans for the lesson—will help you engage your students in a meaningful science activity *and* invite them to think about, reflect on, and construct ideas from this activity?

There are many lesson plan templates or guides to help you get started. They are usually designed to predict the behavior of your students and of you as a teacher. But I have dedicated a great deal of this book to helping you understand that you *cannot* always predict where a meaningful science activity or investigation will lead. In Chapter 2, Mr. Wilson could not have anticipated the ways in which his students chose to weigh the icicles. He understood that there would be many varieties of experimentation when he asked the students to take control of the exploration. The goal, then, is to create a plan that allows for flexible procedures and critical thinking about the lesson. Further, there are many science lessons aligned with the national standards online. Research shows that teachers who modify these online lessons to meet the specific parameters of their class teach lessons that result in greater learning gains for the students (Littenberg-Tobias, Beheshti, & Staudt, 2016).

The guide that follows is one useful model and can get you started in the planning process. Over the years, it has been modified by many teachers as a result of their actual experiences doing science with students. As you begin working with other teachers and see different ways of planning, you too may modify the plan to meet your own personal needs.

12-5 A Planning Guide

The feature "A Guide for Making a Science Lesson Plan" lays practical steps for science lesson planning. Each step is a question that you ask yourself. Notice how the steps correlate with the five phases of the learning cycle that you read about early in this book: engagement, exploration, explanation, elaboration, and evaluation.

To illustrate how to use these steps, let's say that you are writing a lesson plan for an exploration of earthworms like the one described in Chapter 6. The students will be exploring the features of the earthworm with a partner using a magnifying lens and a paper plate. It is useful to start with the Goals and the Disciplinary Core Ideas before you describe your procedures.

12-5a Goals

What am I hoping the students will get out of this science experience? This part of your plan asks you to state the problem or phenomenon the students are exploring and what you are hoping they will learn. In the earthworm lesson, you might say:

I am hoping that the students will notice that:

- *The worms are segmented.*
- *They are soft and secrete a mucus to keep their skin moist.*

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A Guide for Making a Science Lesson Plan

Answer fully each of the questions listed below.

Goals	What am I hoping the students will get out of this science experience?
Disciplinary Core Ideas	What are the *science* ideas at the heart of this experience? What concepts am I hoping the students will understand as a result of this lesson?
Procedures	
Engage	How will I attract students' interest in the topic?
Explore	*Science investigation:* What will the students be examining and exploring on behalf of their own learning?
Explain	What kind of meaning will students construct from this experience? How can I help students by scaffolding their ideas? Can they argue from evidence?
Elaborate	How will the activity connect to what we have been doing in class? To the students' lives? How will I help the students organize their thinking and pull this lesson together?
Evaluate	How will I know what the students have learned?

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- *They have no internal skeleton.*
- *Invertebrate animals do not have an internal skeleton.*
- *The earthworm's structures are related to its functions.*

12-5a Disciplinary Core Ideas

What are the DCIs at the heart of this experience? What concepts am I hoping the students will understand as a result of this lesson? In this step, you state the science concepts—the underlying ideas about the natural world that you are hoping the students will construct as they engage in and reflect on the activity. For example, in the earthworm lesson, you could write:

- *Earthworms are invertebrate animals with long muscles and circular muscles that help propel them forward.*
- *They have tiny hairs that help them to slow down or stop.*
- *They have a mouth on the first segment of their bodies, and they have a thick part, called the clitellum.*
- *They have rings around their bodies separating their segments.*
- *These are related to DCIs: 4-LS1-1 and 4-LS1-2.*

12-5c Engage

In this phase, often called the *hook*, you ask yourself how you will command students' interest in the topic. Also called "motivation," this part of the plan engages the students in the topic at hand by exposing them to a curious event (remember the balloon that didn't pop?) or just by showing them the materials

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they will be exploring in a way that arouses their interest. For the earthworms lesson, you might begin with the following question and explanation:

- *Some of you may have had the chance to plant seeds or plants in the soil in an outside garden.*
- *If you dig into the soil, you may find worms that live there.*
- *They are called earthworms, and we have the opportunity to explore earthworms right here in our classroom!*
- *Take out earthworms and place two on a paper plate. Walk around the room and show the worms to the students.*

12-5a Explore

This phase describes the science investigation or activity. What will the students be examining and exploring on behalf of their own learning? For the earthworm lesson, you might write:

- *The students will work in pairs to explore the external features of the earthworm.*
- *Each group will have magnifying lenses and two worms on a paper plate.*
- *Encourage the students to keep their rubber gloves on when handling the earthworm.*
- *Ask them to draw their worms in their science notebooks.*

Often there is a materials list in the Explore section of the plan. For this investigation, materials include:

- Disposable rubber gloves
- Paper plates
- Magnifying lenses
- Earthworms
- Be sure the large jars with soil that will be the earthworm's classroom home are ready, so the students may return the worms after their activity.

It is important, of course, to add quantities to your list so that you have enough materials for all the students to participate. How many paper plates, rubber gloves, earthworms, and magnifying lenses? How many large jars?

12-5a Explain

What kind of meaning do students construct from this experience? How can I help students by scaffolding their ideas? How can I encourage them to argue from evidence (SEP 7)? Any advance thinking you do about your role as a guide and mediator belongs in this section of the lesson plan. You may want to include key questions that you will ask the students during the lesson—for example, questions that will encourage them to use certain SEPs. For the earthworm lesson, these questions could include:

- What do you notice about the earthworms? List your observations; draw your specimen in your notebook.
- How do you think the earthworms move?
- What propels them forward?
- How many parts or segments do they have?

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12-5f Elaborate

How will I help the students organize their thinking and pull this lesson together? In this part of the science lesson, you give students the opportunity to formulate and express some of the science concepts they have developed from their experiences. For the earthworm lesson, you might plan the following:

- *Have students talk about their observations of their earthworms and write them on poster paper or record them on the classroom SMART Board.*
- *Gather students' ideas about how the earthworms move and how they eat.*
- *Students can also suggest functions for the thick part of the earthworm.*
- *Introduce the term* invertebrate *to describe the animal's classification. Introduce the term* clitellum *to describe the earthworm's thick part.*
- *Students may want to look up information about the earthworm on their classroom computers.*

12-5g Evaluate

How will I know what the students have learned? Here you are checking for understanding, not mere facts. You can plan an activity, a writing exercise, or a formal assessment. You will want to see how the students' learning fulfills your original goals and any further goals that have evolved along the way. To evaluate the earthworm lesson, for example, you could ask your students to complete a *minute paper.* This is a one-minute exercise in which you distribute index cards or small pieces of paper and ask the students to write two things they have learned about earthworms and two questions they may have. This assessment will help you to plan for future lessons.

12-5a If I Know It, Do I Have to Write It?

In the preceding section, you probably noticed the assumption that you would be *writing* your lesson plan. But you may have been thinking, "Is it really necessary to write the plan? Isn't thinking about it enough? After all, I'm not going to stop in the middle of the lesson and pull out a written plan."

For most teachers, writing your lesson plan down is important, whether or not a written plan is required by your school. It is a way to collect and represent your thoughts, then save and modify them as you go along. Writing the plan down is another step toward becoming a reflective teacher. You should think of the document itself as part of your own teaching journal. It becomes a tool for you to reflect on, use again, and change over time. Many teachers develop their lessons in a word-processing document and save them electronically so they can be modified and refined each time they are used. The more you actively engage in planning, the greater the chances are for student learning.

I still have lesson plans that I hand-wrote during my first year of teaching. The papers, now yellowing, remind me of how my thinking has changed in some ways and remained the same in others. I know that the process of writing these plans helped me and my students, and it continues to do so.

12-5f Time Allotment

Your planning instrument becomes a tool for creating a science lesson in which the students have the opportunity to explore, reflect, and explore again. Sometimes one lesson plan will take you several days or more to implement.

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You may wonder how to carry out such a plan in middle school, where you often have only forty minutes per day for the science period. Think back to Chapter 7, where Mr. Hutcheon created a sustained inquiry about floating and sinking by spreading it out over a number of days, sometimes using a single period of science, other times a double period. Sometimes, in middle school, teachers take doable "pieces" of an investigation and perform those in the allotted time, asking students to reflect on the experience for homework. It is important then to keep building on the prior day's activity with your students. Remember also that older students will require less time for distributing and cleaning up materials. In most cases you can plan thirty minutes for the activity itself, leaving only ten minutes for setup and cleanup. In elementary school, where you have more flexibility in your allotment of time, I suggest that you follow two principles:

1. Allow at least one hour of class time for engaging students in any scientific activity, even a fairly simple one.
2. Always build in the flexibility to spend more time on an activity than you originally thought would be required.

12-6 After the Planning, the Letting Go!

Now that you have planned for the science lesson and organized the materials, how prepared are you to abandon your plan and respond to the students' interests, ideas, and questions? Remember the science story about Ms. Drescher's class in Chapter 7, when the students explored liquids? In that case, a fairly simple lesson turned into several days' work on density, a concept that was not in Ms. Drescher's original plan. Remember the milk waste project in Vermont in Chapter 11? The investigation emerged as Ms. Rhodes engaged the students in the topic of conservation. Although she did not plan to measure the milk remaining in the cafeteria containers, her ability to build on the students' interests made the learning experience a success.

Some teachers are so pleased with their lesson plans that the plan becomes an instruction manual for the lesson *rather than a useful guide.* This prevents the teacher from letting go of the plan even when the students' own ideas have taken the lesson to another level of awareness. As you have gathered from the stories in this book, you will often find that your students have questions that emerge from the investigation at hand! You will even have students who ask you directly if they can try a certain experiment that was not in your original plan. More often than not, if appropriate materials are available, it is a good idea to encourage the students to explore these problems of emerging relevance.

But how exactly will you know when to let go of your plan? Be assured that careful planning will give you the confidence to let go. This is because you will be able to evaluate the science concepts connected to each topic and consider the possibilities for students to expand their thinking through new investigations. And the more experience you gain, the more comfortable you will be in thinking on your feet.

Here are some situations in which you can reasonably modify or abandon your original plan:

- The science concept that you were hoping would emerge does not.
- Students reveal alternative conceptions that are resistant to change. (Think about the bottle-and-balloon story in Chapter 2, when the students needed to explore different setups before they would abandon the idea that the air came from outside the bottle.)

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A Planning Checklist

Before you complete your lesson plan for the science experience in your classroom, the following checklist can help you decide if you are fully prepared.

- Have I done enough research of my own? Do I understand the science concepts behind this topic?
- Is it aligned with specific DCIs, SEPs, and CCs?
- Do I need special arrangements for live materials?
- Do I need parental or administrative permission for any of the activities?
- Have I decided what types of student groupings I will construct? What will I ask each group to do? How will the groups share information with each other?
- Do I understand how to guide the students to reflect on the activity?
- Have I allowed enough time for the lesson—and extra time in case my estimate is wrong?
- Am I certain enough of the lesson's goals so I can tell when to modify my plan or let the students follow their own ideas?

- The students want to explore a related investigation that you believe is a good idea. (Think about the liquids exploration with Ms. Drescher, when the students developed an interest in density.)
- One or more students need to explore a phenomenon on their own terms. (Remember how Jamie in Chapter 2 had a different question about icicles.)

It is impossible for you to predict where your students will take an investigation that you and they have planned, but it is important that you listen actively to their queries and encourage creative explorations. Active listening requires that you probe your students' thinking as they develop new ideas. During the pulling-it-together time, the students can share the particular meanings that their explorations have had for them. The entire class will be enriched by the detours and alternative paths that your students will take.

12-7 The Role of Questioning

open-ended questions
Questions that lead to multiple answers. They are especially important because they help students think critically about their science experiences.

Often you facilitate the science experience through the questions you ask your students. **Open-ended questions**—those that lead to multiple answers—are especially important because they help students think critically about the investigation. Frequently, too, the teacher's questions lead students toward their own new investigations. As you read earlier in this chapter, the nature of the questions you plan to ask can form part of your written lesson plan. Now let's take a closer look at the types of questions and the way they can help you guide students.

12-5a Types of Questions

Your questioning can be categorized in many different ways. We will consider three types of questions: (1) questions that invite students to action—using their senses to make observations, for example; (2) questions that access students' own ideas and prior knowledge; and (3) questions that help you check for understanding.

> *The central purpose of questioning is to ask or promote the asking of questions that foster deep understanding rather than questions that ask for repetition of memorized information and conclusions.*
> —Jim Minstrell and Emily van Zee (2003)

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12-7b Questions That Invite Students to Action

Often you can use open-ended questions to invite action and encourage students to apply various process skills. Table 12.2 offers samples of questions that promote the use of certain skills. Of course there are many other questions you can use and many useful ways of phrasing each question.

12-7c Questions That Access Students' Own Ideas and Prior Knowledge

Sometimes questioning techniques point students toward certain topics, much like the focusing questions at the beginning of the chapters in this book. Such questions invite students to come up with their own ideas about a specific topic or investigation.

Here are some examples of questions that access students' ideas or prior knowledge related to the earthworm investigation described in the sample lesson plan:

- How would you describe the way the earthworms move?
- How would you test how far your worm moves in twenty seconds?
- How are these earthworms the same as or different from others you have seen?
- How do earthworms take in their food?
- What type of investigation could you design to explore your earthworm's reaction to light?
- What do you think it means for earthworms to regenerate?

TABLE 12.2 Sample Questions and Related Behaviors/SEPs

Question	Student Behaviors and SEPs
What do you notice?	Observation (SEP 8)
Why do you think this is happening?	Inference (SEP 7)
In what ways are these things the same?	Comparing (SEP 8)
In what ways are these things different?	Contrasting (SEP 8)
How would you group these objects?	Classifying (SEP 7)
What do you think will happen?	Predicting (SEP 6)
How would you test this idea?	Planning an investigation (SEP 3)
How would you change this experiment if you repeated it?	Planning an investigation (SEP 3)
On the basis of what you did, what sense do you make of the data you collected?	Interpreting data and drawing conclusions (SEPs 7, 8)
What do you mean when you say that?	Explaining a concept (SEP 6)

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12-7b Questions That Check for Understanding

Teachers often get into a pattern of asking questions to elicit single correct answers and then move on to the next question. This often leads students to think that science is about "right answers." Rather, we need questions that inspire students to reveal their thinking so we can use what they understand or what they have missed as a way to move forward with the lesson.

This does not mean that your questions need to be complicated. Often the simplest question can challenge students to think deeply about an experiment or an exploration. My favorite example is, "So, what do you think is going on here?" I use this question to invite students to articulate the meaning they are making of an event.

We also assess student understanding when we ask them to *apply* what they are learning to another context—for instance, when we ask how the phenomenon they are exploring may relate to something they have seen in their daily lives. With the earthworm lesson, you might ask your students, "What other animals have you seen that move like earthworms?"

Another way to evaluate students is to ask them simply, "What did you find out from this investigation? Can you write it in your science notebook?" Or you can ask your students what they liked about an exploration, what they didn't like, and, most important, "How would you change it?" Questions of this type encourage students to think critically. In addition, requiring students to commit their thoughts to writing helps to develop their skills in communicating about science and scientific processes. This process parallels the way scientists function as they carry out their research. They make tentative conclusions, try to connect their ideas to other ideas, and record their findings in their notebooks.

For older students, it is fair to ask them to create their own theories about a phenomenon they have observed. Remember Chapter 8, when Ms. Murray asked her eighth graders to toss a beanbag frog to each other to prompt them to share some of their invented theories about how the particles in an atom's nucleus stay together.

Finally, questions that check student understanding can give you windows into your students' thinking and let you know if they have developed alternative conceptions. Remember that unless you invite students to tell you what they are thinking, a true exchange of ideas cannot take place.

12-7b Don't Rush: A Word about Wait Time

wait time
The time that elapses between the moment a teacher asks a question and the moment the teacher selects a student to respond, offers a clue, rephrases the question, or otherwise moves ahead with the lesson.

Whether you are asking students questions in their small groups or addressing the entire class, it is very important to allow them ample time to respond. **Wait time** refers to the time that elapses between the moment you ask a question and the moment when you select a student to respond, offer a clue, rephrase the question, or otherwise move ahead.

A great deal of research documents the value of providing significant wait time. Studies conducted across grades kindergarten through 12 have compared longer average wait times (generally three to five seconds) with shorter ones (often one second or less). These studies indicate that the longer wait times raise the quality of the student–teacher interactions and the level of the discourse (Chuska, 2003; Rowe, 1974, 1987; Tobin, 1986). Further, research studies indicate that questioning during classroom teaching is unproductive without wait time for students to think before answering (Treagust, 2007).

Wait time provides an opportunity for the students and the teacher to think about the exchange and process their ideas. In whole-class exchanges, researchers believe, longer wait time increases the number of students who participate, so more than just a few students respond. Similarly, in small-group exchanges, longer wait time helps engage all the members of the group.

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Four Keys to Good Questioning

1. Ask a question only if you are truly interested in knowing what the *students* are thinking.
2. Design questions to help students construct their own answers.
3. Always employ appropriate wait time to foster participation and higher-level learning (Tobin, Tippins, & Gallard, 1994).
4. *Never* answer your own questions! It is better to leave a question unanswered for a while than to answer it yourself. The questions you ask the students are always more important than the answers you give them.

The literature about wait time has been widely accepted in science education, and yet many teachers continue to rush to call on students. Often this occurs because we are not used to silence in the classroom. Sometimes teachers feel so uncomfortable when students do not respond after five seconds that they answer their own questions!

12-8 Science Learning Groups: Creating an Environment for Team Work

You may have wondered why so many of the science stories in this book feature classrooms in which students are learning in small groups. The teachers in our science stories created environments that nurture collaboration among students. The basic reason is that science and engineering practices including the processes of investigation, reflection, and further investigation, whether undertaken by third graders or by adult scientists, benefit greatly from the collaboration of several people. In addition, research has shown a number of positive results from students' cooperative learning, as we will see in a moment.

In this section, we address several important questions surrounding the small-group model of teacher and student interaction:

1. How do small-group investigations in science relate to what educators call cooperative learning?
2. In what ways is small-group learning consistent with constructivist views of learning?
3. In what ways is small-group learning consistent with the way science and scientists operate?
4. How can I set up small-group learning in my own classroom?
5. How can technology help me engage students in small-group learning?

12-5a Learning Groups

cooperative learning
An instructional approach in which students work together in groups to accomplish shared learning goals.

Extensive research has been done on small-group learning, often labeled **cooperative learning,** which can be defined as students working together in groups to accomplish shared learning goals. Studies have shown a variety of both social and educational benefits from cooperative learning. For example, cooperative learning helps students retain more conceptual knowledge. It also fosters a classroom climate in which students interact in ways that promote each other's learning (Johnson & Johnson, 1999; Slavin, 2009).

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It is important to recognize, though, that cooperative learning, as the researchers in this field define it, is not just any small-group instruction. It is a particular way of organizing the social interaction among students. If four students sit passively while a teacher talks at them, that may be small-group instruction, but it is not cooperative learning. A **cooperative learning group** is an arrangement in which a group of students, usually of mixed ability, gender, and ethnicity, work toward the common goal of promoting each other's and the group's success. In other words, in a cooperative learning group, each student is responsible for his or her own learning *and* the group's learning.

cooperative learning group
An arrangement in which a group of students, usually of mixed ability, gender, and ethnicity, work toward the common goal of promoting each other's and the group's success.

There are many ways to structure such learning groups. One basic distinction is between formal and informal groups. In *formal* cooperative learning groups, the group stays together until the task is done. In *informal* groups, the commitment is for a shorter term, as when each student checks with a neighbor to see if he or she understood (Johnson & Johnson, 1999, p. 15). The science stories in this book have involved formal learning groups, which stayed together until the problem was solved, the model was built, or the task was accomplished.

To be effective, cooperative learning must provide a good deal of structure for the group, and it must be supplemented with direct involvement by the teacher. You saw an example of this in Chapter 9, when Ms. Travis gathered the attention of the whole class to explain the meaning of the term *circuit* to the entire group. Another example is when teachers address the entire class to gather ideas from students before and after a science activity.

12-8b Small-Group Learning Works

Cooperative learning groups, such as the ones you have seen in this book, encourage the very constructivist learning processes that are at the heart of gaining conceptual knowledge in science. In such groups, students have the opportunity to discuss their ideas with others, discover differences between their own explanations and others', and defend their positions or alter their thinking as the group strives for consensus. Why is this interaction so important for learning? There are many reasons, but here we concentrate on three: reflection, the social context of learning, and the implications of cultural diversity and gender.

12-5c Cooperative Learning and Reflection

Throughout this book, as we have explored the ways students best learn science, we have seen that science teaching and science learning rely on the active participation of students. But we have also seen that students must be mentally active as well as physically engaged with activities. In this chapter, by saying that an activity is not a lesson, we have stressed the need for reflective mental processes to accompany the concrete activities.

Small-group, cooperative learning fosters these all-important processes of reflection. When students exchange and clarify ideas with their peers, plan an investigation, or refine their observations and conclusions, their minds are constantly engaged. Each student is prodded to more reflection by the inferences and opinions of others. The collaborative problem solver goes further in constructing new ideas and becomes better prepared for higher levels of thinking. The teacher is also a collaborator, visiting each group and helping it to focus.

12-8b Learning in a Social Context

At the beginning of this book, I noted briefly how our understanding of the world is constructed in a social context. Even if you disagree fervently with your neighbor about, say, the value of exploring Mars, you both are working

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with many similar concepts, including understandings of what and where Mars is and what kinds of exploration are feasible. You are both also using similar language.

In the same way, students' construction of new science explanations and theories is influenced by the social communication and language norms of our society. Peer communication in a small group helps the group's members find a common language with which to express their meaning, and this process promotes their learning. For example, in a lesson on density, the textbook might say, "Density is the mass divided by the volume." This type of decontextualized language can be baffling to many learners. But in a small-group conversation, the students may talk about how much 100 milliliters of corn syrup weighs and whether they think the corn syrup is denser than the corn oil. One student may then weigh 100 milliliters of corn oil and find out that it weighs less than the corn syrup. As this more contextualized meaning for density emerges from the common social discourse of the small learning group, each student can develop a more personalized, deeper understanding of the science idea. This is especially helpful for English language learners.

12-8e Cultural Diversity and Gender in Cooperative Learning

As we stated earlier, images of scientists have traditionally excluded women and minorities. We know, too, that students who see themselves as marginal in a large group do not readily participate. Thus it is not surprising that girls and students of minority ethnic and cultural groups all too often distance themselves during science lessons, contributing little and learning little.

Cooperative, small-group learning activities can help solve this problem. For girls and culturally diverse science learners, these activities attend to their academic needs far better than do individual learning activities (Barba, 1998; Bruna & Gomez, 2009). Group work and cooperative learning can reduce individual competition and raise the level of cooperation (Diamantes, 2002), and the climate of support encourages the participation of students who are less likely to volunteer and interact in a whole-class situation.

We should not forget, too, that getting culturally diverse students involved benefits everyone else in the group. Remember the story in Chapter 6 of Ms. Byrne's third-grade class, which was investigating fruits and vegetables? The students, who were from several cultures, shared information about foods that were familiar and unfamiliar to them. This type of interaction expands everyone's knowledge and often leads students to develop further questions to investigate.

As we will explore later in this chapter, students with physical or learning disabilities also contribute to the diversity of a cooperative learning group. They bring a way of seeing the world that enhances the science experience for all the group's members.

12-8e Scientific Investigation and Group Learning

In the adult world, scientific investigation is a social process. Scientific researchers collaborate with one another all the time. They work on teams; they share references to important articles; they access others' research through electronic communication and the Internet.

Classroom science learning groups are a real-life model of the collaboration necessary for true scientific inquiry to occur. They help eliminate the false stereotype of the lone scientist in a remote laboratory. They promote the kind

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of interchange and teamwork that are essential for scientific problem solving. Moreover, by fostering interactions among students who normally would not be relating to one another, they widen the range of students' observations and increase both the breadth and the depth of classroom investigations. The more diverse the perspectives on nature are, the greater is the likelihood of thorough explorations of natural phenomena. In addition, scientists agree that greater diversity in observations and inferences leads to a higher possibility that an accurate idea will emerge in the conversation.

12-9 Structuring Cooperative Learning Groups in Your Classroom

As we noted earlier, cooperative learning groups need structure. For the learning to be successful, the groups and their activities must be carefully selected. There are many different ways of structuring the groups, but some questions will always arise: Which students should be in which groups? What individual roles need to be assigned within a group? And how should I, as a teacher, mediate learning for the various groups in my class?

12-9a Assigning Students to Groups

Most small learning groups are created with two to four students. Sometimes groups of five are effective, but usually the smaller, the better. Keeping the group size small may limit the amount of diversity you can achieve within each group. Nevertheless, try to design the groups with as much heterogeneity as possible. Students of mixed ability, gender, and ethnicity should have the opportunity to work together toward common goals, learning about one another in the process.

As a teacher, you should take the lead in designing the learning groups. When students are allowed to select their own collaborators, the groups are often homogeneous, with males working with males, white students working with other white students, and so on (Johnson & Johnson, 1999, p. 23). As a result, students do not interact with a wide variety of peers—one of the goals of cooperative learning.

You may want to gather information from the students before you design the groups. For example, you can ask each student to write down the names of three people he or she would like to work with. With this information, you can build groups that include at least one person of choice for each member. Groups should work together for as long as it takes for them to be successful, but at some point you will want to reshuffle the groups so that each student has the opportunity to work with as many other students as possible.

12-9a Assigning Group Roles

In formal learning groups, each member is usually assigned a particular job or role. This is important not just to promote group efficiency but to make sure that every student participates fully. When everyone has a specific task that is essential to the problem solving at hand, each student will be a valued member of the group.

You may remember that in some of the science stories in this book the teachers used assigned jobs that included the roles of speaker, director, materials manager, and recorder. Another model for designing cooperative learning groups uses three prominent jobs for each group or team. The director makes sure that the team understands the investigation and completes each task in the directions. The manager collects and returns the materials that the team needs. The speaker asks the teacher and other teams when the team requires help. This

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model of three roles is popular in some school systems, and some schools even use printed badges that the students wear to designate their roles (Biological Sciences Curriculum Study, 1996). It is not necessary to use any of these particular labels for the group roles; you may design your own labels if you prefer. Whatever you call the roles, group work flows more smoothly when different students have different responsibilities.

In the model of science learning groups that I often use, the teacher designs the groups, but the members of the group then select a leader, who is usually also the spokesperson responsible for reporting results to the entire class. The leader changes from one investigation to another. The teacher also specifies the other roles to be filled, and the group then selects individuals to fill them.

As you can imagine, it is important for students to understand the responsibilities of each role. As a teacher, you will particularly appreciate the ways in which the group member responsible for getting and returning materials reduces the number of students wandering around the room at a given time. The more complex the investigation and the larger the group, the more roles may be involved. Whatever the assigned tasks for one investigation, the roles should change from project to project.

12-9c Facilitating Group Learning

As the teacher, you manage and mediate the students' groups. You give directions for establishing the jobs and assigning the tasks, and then you facilitate the change of jobs when a new investigation begins. You can promote effective group work by monitoring how the group is functioning and making suggestions (Johnson & Johnson, 1999, pp. 42–45). Reminders to individual students like, "Did you check with your group?" or "What does your group think?" can help promote the value of the group.

One method for monitoring the group process involves a cooperative learning structure called "numbered heads together" (Kagan, 1997). The teacher asks the students to number off within groups. In four-person groups, for example, each student would be number 1, 2, 3, or 4. The teacher can then pose a question and ask the groups to "put their heads together" to make sure everyone in the group agrees on the answer. After the group members have consulted among themselves, the teacher calls out a number—3, for instance—and the students whose number is 3 raise their hands to offer their group's answer. Each time a new question arises, the teacher calls out a different number. This technique can be used to check that each student in each cooperative learning group is participating in the group's decision making.

Different groups will make different decisions about how to proceed with scientific investigations, and it is important to honor and value these differences. Sometimes it will even be necessary to allow an individual to go off on an investigation by himself or herself, as Mr. Wilson did with Jamie in Chapter 2. At the same time, however, you need to coach and prompt the groups as they struggle toward problem solving. When appropriate, offer ideas, provide focus, or give specific explanations of the problem at hand.

When the investigation is complete, invite the members of each group to discuss how well they collaborated with each other. Their comments will help you to evaluate the groups' effectiveness and plan for the next group science activity.

As you create this model in your own classroom, you will find that small-group cooperative learning is truly essential to doing science with students. You will see for yourself that the groups encourage the process of problem solving in ways that individual instruction cannot. You will also see the value of diversity in group problem solving.

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12-9a Cooperative Groups across the Globe

The National Space and Aeronautics Administration (NASA) offers a program for middle school students, called NASA CONNECT, that engages groups of students in projects that connect science to mathematics and technology. NASA CONNECT lets students become involved in science and engineering activities through school-to-school collaborations and through materials and videos made available at the website. Students from one middle school, for example, can collaborate with students from another middle school to solve a challenge. In one example, the challenge was titled "Better Health from Space to Earth," and students were asked to work in groups to develop daily meal and exercise plans for individuals with special needs.

Another NASA program, NASA Live, offers videoconferences that connect researchers with students throughout North America and beyond. Each videoconference engages the students in an interactive experience, including a variety of multimedia activities. Teachers and students exchange ideas with NASA experts in science and engineering. This type of cooperative group work transcends classroom boundaries and fosters science learning groups across geographic areas.

12-10 Inclusive Science Education

Our goal as science teachers is to offer opportunities for all students to gain sufficient schooling in science in order to become better problem solvers, critical thinkers, and inquiring human beings. In the opening chapter, we discussed *differentiating instruction* so that all students can participate in a science education experience that maximizes the possibilities for their success. We also noted that designing science instruction for all learners involves using multiple approaches with many types of activities and materials and that this type of universal design ensures that all types of learners are engaged in the science experience. We want all students, including women and ethnic minorities, to feel *entitled* to success in science.

Feeling entitled to success in science is often based, as you have seen, on long-held stereotypes that persist in the media and in our minds. Every year in the United States, we celebrate Women's History Month and Black History Month to remind students that those who came before us made significant contributions to our lives today. Among those contributions are advances in science and technology. Each year, therefore, I would ask my sixth graders in middle school to research a woman and/or a person of color who had contributed to advancing knowledge in science and technology. Instead of writing a report, I would ask them to design and construct some artifact that represented their chosen scientist's life or work. Students who researched the life and work of Nobel Prize winner Barbara McClintock, for example, learned that McClintock worked extensively with corn plants in order to discover that genes can move from one place to another on their chromosomes, causing mutations. For their artifact, these students designed and constructed a three-foot model of an ear of corn. Each corn husk in the model had data about Dr. McClintock pasted on the inside of the model leaf. Hence, the artifact represented her work and provided information about her. I strongly urge you to develop similar projects with your students, and not just during special months of the year.

People with disabilities are another group that commonly receives little encouragement in science. Did you know, however, that one of the world's most eminent marine biologists is blind? A professor at the University of California—Davis, this scientist's work is with mollusks, those shelled invertebrates that inhabit marine waters. His extraordinary sense of touch enables him to study these creatures and make observations that elude other scientists. His name is Geerat J. Vermeij, and he has won several honors for his work (see the feature "Geerat Vermeij Speaks about His Work").

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Learners may have special needs because of a wide variety of learning disabilities, behavioral problems, or physical or sensory impairments (Hardman, Egan, & Drew, 2017). In the following sections, we will discuss some of the differentiated instruction tasks that work best for students with disabilities. There are many websites available to assist you with instructional strategies. Remember, our goal is to make it possible for *all* students to do science in the classroom.

12-10a Science and the Inclusion Model

The Individuals with Disabilities Education Act (IDEA) and the Americans with Disabilities Act (ADA) extend equal opportunity to those with disabilities so they can experience the same services that have always been accessible to the general population. Under these laws, students with disabilities are not receiving something extra; they are merely gaining access to what the general population has taken for granted (Stefanich, 2007). Similarly, science education reform documents support science education's goal of scientific literacy for all, regardless of any categorization of learners' abilities (McGinnis & Stefanich, 2007).

inclusion model
The practice of placing students with disabilities in regular classrooms to the greatest extent possible.

These laws and reform documents lie behind the **inclusion model,** in which students with disabilities are placed in regular classrooms to the greatest extent possible. Findings in educational research support the inclusion model as a more desirable alternative than segregated instruction for students with disabilities. This is true regardless of gender, race, ethnicity, social class, or type of disability.

When "inclusion students," as they are often called, are placed in a regular education classroom, a special educator is usually available to offer support. What has sometimes happened, however, is that the regular classroom teacher has little to do with the development of the student's individualized education plan (IEP). Therefore, the regular teacher ends up presenting the science curriculum content without knowing much about the needs-specific pedagogy. At the same time, the special educator, who knows how to teach students with special needs, does not know enough about the regular content to relate it to the special pedagogy. Hence the student's science education gets lost in the gap between the teachers. To avoid this problem, it is important for the regular educator and the special educator to work as partners from the beginning.

Geerat Vermeij Speaks about His Work

I study the history of life. I want to know when evolution occurred and when it did not. Although my research is concentrated on fossil and living shell-bearing animals like snails and clams, I apply the results to large scientific questions. I am especially interested in looking at the history of life on Earth from an economic point of view. This involves the study of technological innovations, the analysis of how workable ecosystems are constructed and maintained, and an understanding of how shifting availability of resources affects the everyday affairs of organisms in past and present ecosystems. The ultimate aim is to see what the economic history of life can tell us about how to construct human economies that are not dependent for their health on perpetual growth. On the way to these lofty goals, I am having a great time studying the classifications, architecture, and history of snails, whose beauty rivals that of any human artistic creation.

Source: "Geerat Vermeij Interview," Department of Geology, University of California, Davis.

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Fortunately, the best science teaching practices—engaging students in using all their senses, in manipulating materials, and in asking questions—represent the type of multimodal approach that is also very successful for students with disabilities. While by no means comprehensive, the following section offers some strategies for helping special education students achieve success in learning science.

Before we begin, however, let's remember what all students need: They need to know that their teacher expects them to succeed and is working hard on their behalf. Holding out the expectation that your inclusion students will be successful in science is an important first step. Remember, you teach who you are.

12-10b Classroom Strategies for Doing Science with Students with Disabilities

Several general strategies are useful for students with any type of disability:

- Allow more time for students with disabilities to complete the task at hand. This is an important step, and it should become routine in your classroom.
- Get feedback from your students with disabilities. Ask, "How am I doing?" "Are you having a particular difficulty with this science experience?" "What are you most pleased about?"
- Explore technologies that can help. Software programs can benefit students with many kinds of disabilities. In addition, there are science tools and materials that help students complete scientific tasks, for example, beakers with special holders, pouring spouts, and larger numbers for calibration.

The following subsections offer a number of suggestions (adapted from Stefanich, 2007) for teaching students who have particular kinds of disabilities. See also the feature "Classroom Survey: How Accessible Is Your Classroom?"

Motor/Orthopedic Disabilities The term *motor/orthopedic disability* encompasses a large number of impairments involving functional or structural aspects of one or more body systems. Examples include cerebral palsy, polio, muscular dystrophy, multiple sclerosis, and spinal cord disorders. Experts find the following instructional approaches useful:

- Review work areas for appropriate height and accessibility of supplies.
- Examine the classroom environment and make sure the student has appropriate access to other students.
- Examine the students' movement patterns and needs. If necessary, rearrange classroom furniture and other objects so the student can move around as needed during a lesson.
- Provide accessible means for reviewing drawings, charts, or graphs.
- Look for adaptive computer software and other special equipment. Contact assistive technology agencies directly, and become familiar with the specialized equipment.

Visual Impairments People with visual impairment are often characterized as having either "low vision" or "blindness." If they have low vision, they may be able to read with the help of large print or magnifiers (Hardman, Egan, &

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Classroom Survey: How Accessible Is Your Classroom?

The following survey was developed to help you assess your classroom in terms of its accessibility for students with disabilities. You will notice, though, that many of the items refer to excellent science learning experiences for all students.

What is the average width of the aisles?

_____

(Aisles should average 42 to 48 inches minimum. This allows access for students in wheelchairs and those using other assistive devices.)

Describe the work surfaces, lab tables, and so on.

_____

_____

_____

(Spaces under work surfaces should be 29 inches high, 36 inches wide, and at least 20 inches deep. The work surface should be no more than 32 inches off the floor. This allows access for students in wheelchairs and those using other assistive devices.)

Is safety equipment (fire extinguishers, eyewash, fire blanket, first-aid kit, and so on) easily accessible?

_____

(This is important for all science classrooms.)

What types of projection devices are used in the class? Overhead projectors? Data projectors used with computers?

_____

(Projectors are a useful visual aid for all students.)

What are the light conditions in the room?

_____

_____

_____

(The quality of lighting has implications for all students' learning.)

How are the acoustics in the classroom?

_____

_____

_____

(Again, your answer has implications for all students' learning.)

How are things stored in the room? Consider both the accessibility of desirable materials for doing science and the importance of keeping more dangerous materials, like hot plates and matches, in a locked facility.

_____

_____

_____

Source: Adapted from "Making Science Accessible and Inclusive: Strategies for Teachers in Science Education," a preconference workshop presented by Greg Stefanich, Marcia Fetters, Eric Pyle, Dawn Pickard, and Jim Ellis at the Association for the Education of Teachers of Science International Conference, St. Louis, Missouri, January 2003.

Professional Resource Download

Drew, 2017). People with blindness may be unable to gather any visual information. Here are some ways to differentiate instruction for students with visual impairments:

- Use tactile or auditory signals when appropriate.
- Provide a magnifier if the student wants one.
- Clearly label all items and equipment involved in a lesson.
- Allow for direct manipulation of materials when appropriate.
- Provide enlarged handouts.
- Get thermoform sheets. (Thermoform is a plastic sheet material used for duplicating in Braille.)

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- Provide a supportive peer assistant to work with the student.
- Allow the student and his or her peers to continue with science activities outside of the school day or at home.

Hearing Impairments People with hearing impairments can be described by two main categories—those who are hard of hearing and those who are deaf. Individuals who are hard of hearing still have some degree of hearing, which may or may not be enough for them to use auditory information in communication. Deaf persons have no ability to hear.

For your students with hearing impairments, try the following techniques:

- In your classroom seating plan, locate the student where he or she can see your eyes and your lips. Be sure that the background, from the student's point of view, has sufficient contrast.
- Print activity cards in large type so the student can easily read them from a distance.
- Provide a supportive peer assistant to assist during games and construction activities.
- Allow the student and his or her peers to continue with science activities outside of the school day or at home.

Learning Disabilities People who are described as having learning disabilities can suffer from one or more of a number of diverse conditions ranging from dyslexia and attention deficiencies to identifiable brain injuries. The definition of *learning disability* varies between states, and it remains a contentious subject among researchers. Common to most definitions of learning disabilities is the idea of a significantly diminished capability for using and understanding language in spoken and written forms. While students with learning disabilities are of average or above-average intelligence, the disability creates a gap between their inherent ability and their actual performance.

The following suggestions can help you improve your instruction of students who have learning disabilities:

- Eliminate distractions and background noises as much as possible.
- Review directions with students in advance of a lesson or assignment.
- When you interact with a student who has a learning disability, give him or her your undivided attention. Focus on what the student says and listen carefully.
- Be straightforward in your approach. Don't pretend to understand if you do not.
- Allow for noncompetitive participation in classroom activities and games.
- Provide a reader when appropriate.
- Allow for direct manipulation of materials when appropriate.
- Engage students in design and construction activities.
- Maximize the availability of visual materials.

Attention-Deficit/Hyperactivity Disorder (ADHD) Students with ADHD are easily distracted and have trouble concentrating on tasks for any length of time. Some are restless and fidgety, with excessive movements that appear aimless. Some people with ADHD, though—typically females—are quite underactive, and their problem may go unnoticed.

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The following techniques are recommended:

- Position the student with ADHD so that you can visually monitor him or her and exercise proximity control when needed.
- Seek out visual media and models to keep the student engaged.
- Slow down the pace of activities, and allow adequate time for student participation.
- Preview an activity sequence in advance and, when appropriate, write a contract with the student specifying what behavior is expected.
- Be straightforward and direct with the student.
- Allow for interaction with materials when appropriate.
- Allow for time-out if a student needs it.

12-11 Technology to Foster the Success of Students with Disabilities

At one university, a National Science Foundation project has increased the success of people with disabilities in STEM fields (science, technology, engineering, and mathematics). Called DO-IT, standing for Disabilities, Opportunities, Internetworking, and Technology, the program uses computers, assistive technology, and network resources to bridge the communication and accessibility gaps for people with disabilities (Burgstahler, 2006). An easily accessible DO-IT website helps educators access resources and techniques for making their classrooms and science activities more accessible (DO-IT, 2016).

In order for students with disabilities to gain success in science, they should begin using computing and networking tools at a young age (see Photo 12.1). These tools help them to gain access to resources, communicate with others,

Ed Kashi/Corbis

PHOTO 12.1 The goal of inclusive science education is for all students to participate in science with success. Often technology provides a useful aid. Here, students with learning disabilities use laptops as part of their science investigation.

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assistive technology (AT)
Devices or services that promote greater independence for people with disabilities by enabling them to perform tasks that were formerly difficult or impossible.

and perform academic tasks independently (Burgstahler, 2006, p. 16). The term **assistive technology (AT)** refers specifically to devices that promote greater independence for people with disabilities by enabling them to perform tasks that were formerly difficult or impossible. There are many varieties of assistive technology. As you enter your own classroom and become a teacher of science, ask yourself how you may be instrumental in creating positive and accessible learning environments for all students.

12-12 Questions for Your Own Reflection

When the science experience you have planned for your students is over, you may want to document what went on. There is always a lot to write about because you really do not know beforehand where the lesson will go or what the students will say or do. It is the students' thinking that propels you forward. Besides actively listening to the students during the lesson, it is useful to take some time afterward to record their ideas and your own reactions to the way the lesson developed.

Here are some sample questions to ask yourself as you reflect on the lesson and write about it in your science journal:

- What did the students find out in this experience? Were there any surprises?
- How did the students in each group work together? Were there any problems?
- Was the investigation open-ended enough so that students could be involved in the planning? How did the students extend the investigation?
- How did the students connect this experience to their daily lives?
- How did I accommodate students with learning and physical differences?
- Did I use technology effectively?
- Overall, what do I think the students got out of this experience?
- What do I remember most about this science activity?
- Would I do it again? How would I plan differently the next time?

Sometimes it is useful to record comments and reflections directly on the lesson plan itself. Keeping your plans together on a mobile device is a good idea too. Your comments and notes have important implications for how you will address the topic the next time.

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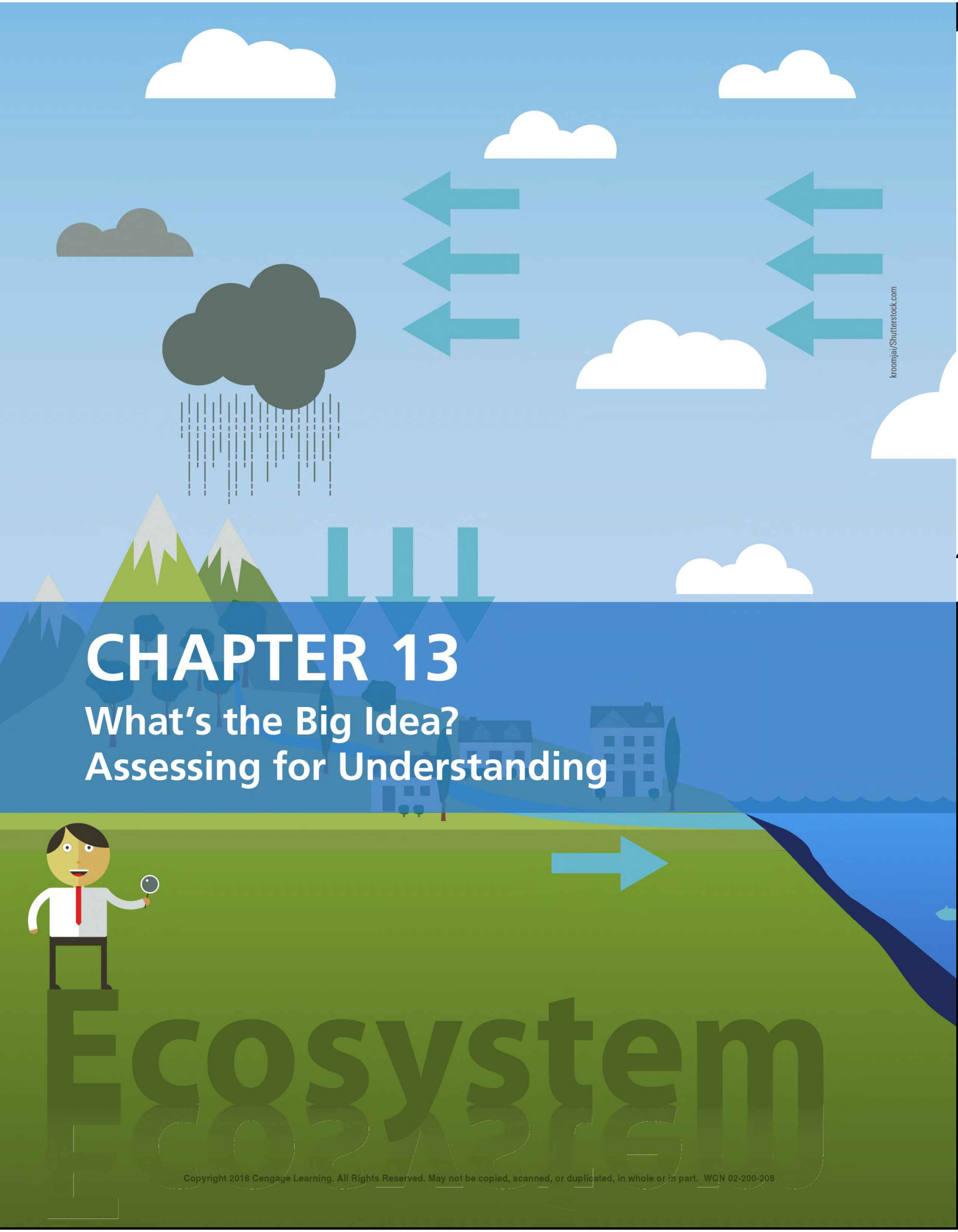

CHAPTER 13

What's the Big Idea? Assessing for Understanding

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 13-1 Explain what is meant by assessment in a meaningful way.
- 13-2 Distinguish among formative, summative, and performance assessments.
- 13-3 Determine how an assessment can be a good instructional task.
- 13-4 Explain how to use science notebooks for assessment.
- 13-5 Analyze how to use writing and drawing exercises for assessment.
- 13-6 Discuss the use of science conversations and interviews for assessment.
- 13-7 Examine how technology can aid assessment.
- 13-8 Explain how using dance and drama can enhance science assessment through performance.
- 13-9 Explain what makes an assessment "authentic."

Reflection

To Think About:

- How do you know if the students understand the concept?
- How can a "performance" be an assessment?
- What is the difference between formative assessment and summative assessment?
- How do teacher-created assessments compare with standardized tests?

When I was in southern Texas working with a group of third- and fourth-grade teachers, they invited me to spend some time with their students. I was interested in learning what the students thought about science—how they would define it, for instance, and how they felt about learning it in school. One day I brought a tape recorder to class and interviewed the students about what they thought science was. This is how it went:

ME: What do you study in science?

THIRD-GRADE BOY: (really thinking) Scienzz, scienzz—what we're learning about scienzz. ... There are stop scienzz, one-way scienzz, and yield scienzz.

My northern accent was clearly unintelligible to this student. He thought I had asked about "signs."

This story reminds me of the many occasions when we are trying to find out what students know but the student misunderstands the very way we ask or write the question. We, as teachers, are seeking one kind of meaning, and our students, with the best intentions, offer another kind. How, then, can we design ways to understand what students really know and are able to do in science? How do we go beyond seeking "right answers" to test questions, for example, to seeking deep understanding of a concept?

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This is the central theme of this chapter. Teachers refer to this quest to determine students' understanding with terms like *assessment* and *testing*. Let's explore what these terms mean in theory and in practice.

13-1 Assessment and Testing

Assessment is an activity that teachers and, in fact, everyone else engage in. We constantly find ways to assess ourselves and others. In education, though, this term is used in specific ways.

science assessment
A process of collecting information that is used to determine the quality and character of an individual or group performance in a science learning experience.

Science assessment refers to a process of collecting information that we use to determine an individual or a group's level of understanding of the science concept. As you might imagine, this process of collecting information about what your students know and are able to do includes many different techniques. When we are teaching, we are constantly assessing. When we engage in conversations with the students, we know who has "got" it by the way they ask a question or respond to the dialog. A student can be fully understanding one science concept but then get stuck by the time the next unit is introduced. Assessment is embedded into lessons and is an ongoing experience. In order to collect formal data in the process of assessing, we ask students to perform a variety of tasks and try to understand if they can apply a concept to a new context. The assessment task we use must have instructional value as well. We ask ourselves, "What can my students learn from this assessment device and what can I learn about my students?"

13-2 Formative, Summative, and Performance Assessments

formative assessment
Assessment that gauges students' understanding of a particular topic in a unit in order to judge their progress and adjust the rest of the instruction accordingly.

summative assessment
Assessment at the end of a unit or course, used to document students' achievement or to evaluate the end product of a student's learning activity.

testing
Assessment of students' learning by means of teacher-made tests or state and local tests designed by educational agencies or testing services.

Formative assessment is used to gauge students' understanding of a particular topic in a unit in order to judge their progress and adjust the rest of your instruction accordingly. In contrast, **summative assessment**, which comes at the end of a unit or course, is used to document students' achievement. Final exams are a typical example of summative assessment (Ravitch, 2007).

Testing is a narrower term than assessment. It refers to the use of teacher-made tests as well as standardized tests designed by educational agencies or testing services. Even within these categories, as you are probably aware, tests come in almost infinite varieties. The phrase *paper-and-pencil tests* generally refers to tests made up of short-answer or multiple-choice questions. Essay tests, in contrast, require longer responses involving students' reflective thinking. Although essay tests may be taken with paper and a pencil, the term *paper-and-pencil test* does not usually refer to an essay test.

Short-answer and multiple-choice tests tend to assess small pieces of knowledge, asking students to recall some term or fact related to the unit of study. Typically, these tests assess knowledge in a fragmented way rather than in the context of the students' learning. As we noted earlier in the book, recalling a term or a piece of knowledge is quite different from constructing meaning. It should not surprise you, then, to learn that paper-and-pencil tests are not the best method for assessing the type of deep, contextual scientific learning that is addressed in this book. To assess that deeper level, educators have been turning to performance assessment. This type of testing assesses "active knowledge"—ideas that can be expressed in a variety of ways.

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performance assessment
A process of judging how well students execute a task as part of solving a problem in a larger context. Often the execution of the task involves a type of student performance. Also known as *authentic assessment*.

In **performance assessment**, students demonstrate their understanding by solving a problem or performing a task in the real-life context of their classroom or their world. As you have seen throughout this book, the act of doing science always occurs in context. Examples of performance assessments include portfolios, demonstrations, and performing an experiment and drawing conclusions from it (Ravitch, 2007). An essay test can be a performance assessment if it is designed to make students think through a problem or question, as we will discuss later in this chapter when we talk about writing as an assessment tool.

Science is not isolated bits of observing, inferring, comparing, or recording; it is instead a contextual whole in which skills are employed because of a need to know. The skills are not important solely for their own sake. In the same way, a performance assessment sets up a need-to-know scenario that encourages the student to employ the skills that the assessment is intended to measure.

Performance assessments, as this chapter will demonstrate, can take a variety of forms. Whatever form you use, it should be appropriate to the context in which you are teaching. In other words, it has to *match the instruction*. In fact, *a good assessment usually looks like a good instructional task*. For example, as we teach science, we engage students in maintaining science notebooks. These notebooks are also used for assessment.

evaluation
The process of examining all the data gathered from various types of assessments to judge a student's or a group's achievement in a learning area.

Finally, the term **evaluation** refers to the process of examining all the data you have gathered from various types of assessments and making a judgment about how well the students understand a concept and use their science skills. Typically, evaluations relate students' progress to their own prior performance and to that of their peers within the class.

13-3 Assessment and the Instructional Context

Assessment is not separate from instruction. Rather, the two join naturally together in the instructional context. As indicated earlier, whenever we are doing science with students, we are engaged in assessment. We wonder, "How are they doing? Do they work well together? What science skills are they using? Are they solving a problem? Do they get the science concept? What kind of model are they constructing?" Assessment and instruction may be thought of as siblings. In this sense, assessment is an integral part of instruction.

It is important to explore your students' understanding in terms of their ability to employ knowledge to make sense of a situation or a problem. In other words, you will be looking at their learning in context rather than just their "possession" of a certain item of knowledge. The following sections discuss several useful techniques for assessment of students' science learning. Remember, learning is an active process of constructing meaning. Assessment can also be an active process that encourages students to express what they know and understand.

13-4 Science Notebooks and Assessment

science notebook
A notebook in which students record their observations, reflections, questions, predictions, and conclusions during a science investigation.

There are many ways to invite students to record a description of the concepts and activities with which they are engaged. I encourage the use of **science notebooks** that describe, in specific formats, the students' investigations as well as their thinking about their findings. The structure of science notebooks directs students to the type of information they need to provide. Within this structure, though, the students' personal ideas about their science experiences have plenty of room to emerge. In this way, the notebooks can become a window into students' understanding of a particular science concept (Photo 13.1).

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Hill Street Studios/Blend Images/Jupiter Images

PHOTO 13.1 A student records her observations in her science notebook, an important step in drawing conclusions about her investigation.

13-4a A Sample Structure for a Science Notebook

One way to structure a science notebook is to use a list of questions as a guide. Students respond to the questions both by writing and by drawing illustrations. Here is a sample list of questions:

1. What do I know about _____? (Prior knowledge)

   For a particular lesson, you would fill in the blank with an appropriate word, such as "earthworms," "electricity," or "seeds."

   For example, in the fourth-grade earthworm lesson described in Chapter 6, a student might respond with the following:

   Earthworms are slimy and yucky. They live in the dirt.

2. What am I trying to find out? (The problem)

   This phase of writing prompts students to define one or more problems relating to the investigation. The students express the main problem they are trying to solve, formulate any other questions they may have, and perhaps think about extensions to the primary activity. By "extensions to the primary activity," I mean ideas that come up as students formulate the question. For example, in this section, a student might write:

   How do earthworms move? What do they do when they burrow down into the soil? What happens when you shine a light on them? Why do we have to put black paper around the worm bottle?

3. What materials do I need? (List of materials)

   Here the students list their materials. In the earthworm lesson, they would note a flashlight for testing the earthworms' response to light, rubber gloves for handling them gently and safely, paper plates, and a magnifying lens.

4. What did I do? (Procedure)

   Once students have answered the first three questions, they proceed with their investigation. Afterward, in question 4, they describe their own activities. In some ways this section is like a log. It provides students with a record of what they did that led to their understandings. It can be written in a series of steps or in a narrative form.

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5. What happened? (The results)

   In this phase of notebook writing, the students document their observations. In the higher elementary and middle school grades, this section may be a formal record of findings, and the students may arrange their data in chart form or in graphs. In earlier grades, when the teacher has done a demonstration, this "what happened" section relates to what the class and the teacher have noticed together.

   Even after a demonstration activity, the science notebook should express the *individual* student's experience with the event. Students may draw or write their observations, or both.

6. What did I find out? (Conclusions)

   In this section of the notebook, students express the inferences and understandings they have arrived at as a result of their investigation. For example, in the earthworm investigation, students might write:

   Earthworms have a mouth but no eyes.

   Earthworms like the soil.

   When earthworms move, they wiggle like crazy and bunch up and then they stretch out.

   Earthworms make slimy stuff called mucus that helps them to move.

   Earthworms make holes in the soil so plants can have space for their roots.

7. What do I think about this experiment [or investigation or activity]?

   In this section, students offer their opinions or ideas about the investigation. Sometimes they make connections to the real world—for example,

   I like exploring the earthworms. I used to be afraid of them but I am not anymore.

8. If I did this over again, what would I do differently? (Reflection)

   This section invites students to analyze the investigation and plan modifications. Sometimes, they start the investigation all over again. This analysis and documentation of their thinking often leads them to important findings. After the earthworm lesson, one student wrote:

   Next time, I would put the earthworm at the top of the worm bottle and watch it go down to the sand part.

The science notebook structure guides students' science writing as well as their science thinking. Notebook entries do not always have to take the same form, however. Sometimes you might choose a question that prompts students to apply their knowledge to other situations or problems. For instance, during a unit on electricity, one fourth-grade teacher had students write the following question: "How can we make a metal item into a magnet that picks up 25 washers using just a simple series circuit and no light bulb?" Students were asked to write their ideas, their procedure for testing their ideas, their predictions, and their results. Under the conclusion section of this structure, one student wrote, "My prediction was not right because I said that if we wrap the wire 40 times around [the rivet] it will get 25 washers and it did not because we only picked up four" (adapted from Klentschy, 2008).

Scientists maintain notebooks that become important sources for their research. Architects, artists, inventors, writers, and others keep journals and sketchbooks that record their ideas and observations and inspire further discoveries. In the same way, science notebooks do more than record students' emerging science ideas; they stimulate additional thinking and investigation. When students look back over the science experiences they have described in their notebooks, they feel a sense of pride. As the teacher, you can use the notebooks not only to assess understanding of particular science concepts but also to learn whether your students are becoming independent thinkers.

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If science notebooks are written by hand, they should always be kept in a bound notebook, not as separate sheets of paper. Like other creative writing products, science notebooks can be created with a word-processing program and kept on jump drives, iPads, or classroom laptops.

Students who keep their science notebooks electronically can easily add to, update, and correct them. If they have ready access to the Internet, they can insert pictures and other images in their notebooks. Sometimes, when the teacher assesses the students' knowledge and learning, the electronic pages are printed out as hard copy and handed in.

13-4b Pictures and Telling Stories

Students can record their observations in drawings as well as in words. Drawing gives students an opportunity to express themselves in a modality other than the verbal-analytic, and this can be an important consideration for classrooms of increasingly diverse learners.

This form of assessment is not limited to the early grades. In fact, older students are often pleased and challenged when they are invited to draw what they have observed and experienced. Older students usually place captions on their drawings as a way to explain the image.

Remember that we are not telling the students *what* to draw. Rather, we are creating an opportunity for them to express their own ideas through the drawing. Nevertheless, the students have to know why we are asking them to draw and what we expect their drawings to contain in order to demonstrate their understanding. In other words, we need to establish criteria for judging the students' drawings, just as we would with any other assessment technique.

In this context, I'm reminded of a third-grade teacher who took her students on a "tree walk" and then asked them to draw a tree and label its "most important" parts. Her minimum expectation was that the students would properly identify trunk, leaves, bark, and roots. Many of her students, however, did not draw the roots because they were underground. Instead, they drew the trees as they had seen them on the tree walk. This clash of expectations can be avoided when the teacher establishes assessment checklists that match the context of the students' experiences.

With young children, it is useful to have them tell a story about their drawings. As they elaborate on what they drew on their paper, the teacher gets an idea of what they know about the topic. This combination of drawing pictures and telling stories is a wonderful assessment tool for early childhood science education.

13-4c Assessing Student Notebooks

rubric
A set of criteria used to determine the scoring value of an assessment task.

For some purposes, you may want to use a specific scoring **rubric** or set of criteria to evaluate your students' understanding on the basis of the writing and illustrations in their science notebooks. The checklist in the feature "Checklist for Assessing Science Notebooks" can guide you.

For purposes of grading, teachers often use qualitative terms for science notebooks—for instance, "unacceptable," "acceptable," "very good," or "excellent." In younger grades, labels like "budding scientist," "scientist," and "super scientist" can be useful.

Whatever system you use to assess science notebooks, you'll find that they give you many insights into the ways in which your students construct meaning. You'll see what the students understand and how they have come to understand it. You'll also discover what, if any, alternative conceptions need to be addressed in subsequent activities.

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Checklist for Assessing Science Notebooks

Assessing for Conceptual Understanding

1. What evidence is there that the student can correctly explain the science concept?
2. Does the student use the vocabulary of the scientific concept accurately?
3. Is there any evidence of student meta-cognition? Are they reflecting on their thinking about the scientific concept?
4. Do the drawings accurately represent their activity?

Assessing for Science as Practice

1. Is the problem or question stated clearly?
2. Can the student list the steps of the investigation?
3. Are observations recorded clearly?
4. Have they stated what was kept the same and what was changed (where appropriate)—constant and variables?
5. Does the student draw conclusions from evidence?

Source: Modified from Shepardson and Britsch (1997).

Professional Resource Download

13-5 Other Types of Writing Assignments

Science notebooks are not the only format for science writing. Many other kinds of writing assignments can serve as both instructional activities and assessments. As an example, one middle school earth science teacher asked her students to write about plate tectonics as though they were explaining it in a textbook. The assignment read this way:

> *You are now experts on the theory of plate tectonics. Pretend you are an important geologist contributing to an earth science textbook. How will you explain this theory in your new book?*

In order to grade this writing assignment, the teacher developed a scoring rubric and shared it with the students. The rubric served as a tool for students to self-monitor; it became their own personal checklist of sorts.

You may be wondering how long this type of assessment takes. You would be correct to assume it takes much longer than a short-answer test and is therefore difficult to include for every unit. It may also require you to make adaptations for English language learners and other students who have a difficult time expressing themselves extensively in written English. Remember the 5R model from Chapter 12. Nevertheless, compared to a short-answer test, this kind of assessment offers a more in-depth perspective on students' understanding of science concepts.

blog
An online journal (short for "weblog"); in education, blogs are personal journals in which students and teachers post their thoughts and observations and others can respond.

Still another kind of science writing assignment involves the use of blogs. **Blogs** are online journals using software that makes it easy for the user to create frequent entries and for visitors to add their own comments and responses. Many of you may be regular contributors to blogs of all sorts. Blogs have become increasingly popular with science teachers because they offer a forum for communication between the teacher and each student and among the students themselves (Photo 13.2). Blogging can be very open-ended and creative, even when students respond to a structured assignment such as the following.

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Arthur Tilley/Creatas/Jupiter Images

PHOTO 13.2 These middle schoolers are writing new entries for their science blogs. Later they will comment on each other's posts, engaging in an open-ended discussion of their scientific observations and ideas.

13-5a Middle Schoolers Blog about Organelles

Mr. Fletcher, a middle school science teacher in the province of New Brunswick, Canada, frequently uses blogs to assess students' understanding. One day during a cell structure unit, when students had been exploring the parts of the cell called organelles, he asked them to respond in their blogs to the following assignment:

> *YOU ARE FIRED!!! You are an organelle of your choice and you are about to be fired. You must defend yourself and explain why it would be a huge mistake to fire you.* (Fletcher, 2008)

The students were allowed to use external links on their blogs as they made their case for the chosen organelle, and they could download pictures to place in their stories. Mr. Fletcher also offered students instructions for posting comments to their classmates' blogs:

> *Choose a blog entry of a fellow classmate. Answer the question they asked in the last assignment. Your response should be thoughtful and based on information you were given or read about in the links.* (Fletcher, 2008)

Each student wrote a blog entry about a particular organelle and then visited classmates' blogs to respond to questions or comments. The students learned from the comments made on their work and from their own reflection on those comments.

Grading rubrics for blogs typically include guidelines for written expression. Students understand that their blogs are for public consumption and may be read not only by classmates but also by others outside of their class (like me!). Blog assignments like this one serve as a useful formative assessment and help students learn with and from their classmates.

authentic assessment
A process of judging how well students execute a task as part of solving a problem in a larger context. Often the execution of the task involves a type of student performance.

Other writing prompts engage students in expressing their understanding in authentic ways. Written essays and the like are considered **authentic assessments** because they contain a variety of documentation representing student understanding in context. As an example of assessment activities that are based on writing, think back to the electricity lessons in Chapter 9. Ms. Travis might offer her students the following prompts:

- Write a letter to a relative explaining how a simple circuit works.

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- Build a five-question game card using hidden electrical circuits. (The game card would be made with materials like aluminum foil, a manila folder, and a circuit tester consisting of a battery, three wires, a bulb, and a bulb holder. Only the card would go into the student's portfolio.)
- Describe the reason that houses should be wired with parallel circuits.
- Explain why circuit breakers are important.
- Using the letters in the word *electric*, write one statement about electricity beginning with each letter.
- Describe an activity that you have done with static electricity. What did you find out?

With an assessment technique like this, students become actively engaged in representing their understanding to the teacher.

13-6 Using Science Conversations for Assessment

science conversation (or science interview)
A direct discussion between a teacher and an individual student about a science learning experience. This activity allows teachers to ask students to elaborate on their ideas—a good way to determine the depth of a student's understanding. Through such conversations, teachers gain important clues about how students construct personal meaning, and these clues then influence future instruction.

Not all students can demonstrate what they know in writing as well as they can in "telling." An oral **science conversation**, sometimes called a **science interview**—that is, a direct communication between an individual student and the teacher—can overcome the problems that are created when we assess students solely on what they can explain in writing.

Chapter 12 stressed the importance of how teachers question their students. But the usual questioning process, even something as simple as, "What do you think about this?" or "Why do you think this happened?" may leave out some members of the class. In personalized communication, you can engage a particular student one on one, find out what he or she is thinking, and negotiate the meanings of any terms that are problematic.

Consider the story at the beginning of this chapter about my visit to southern Texas. After the student and I straightened out the pronunciation difficulty and we both understood that we were talking about science rather than street signs, we had the following conversation:

ME: What do you do when you do science?
STUDENT: We do experiments.
ME: What is an experiment like?
STUDENT: Well, one time we measured how much popcorn we had in a cup. Then we popped the popcorn and measured it again.
ME: How did you measure it?
STUDENT: We filled up other plastic cups with the popcorn and counted how many cups we had.
ME: What did you find out?
STUDENT: We got over twenty cups of popcorn from one cup!
ME: Wow, that's a lot of popcorn.
STUDENT: Yeah, the whole class ate it.
ME: Why do you think there was so much popcorn after you popped it?
STUDENT: Not sure. . . . I think it was something about how big each kernel got when it popped.

You can see that in a science conversation teachers can ask students to elaborate on statements, and in this way they can determine the depth of a student's understanding. Oral interviews such as these have proved to be an effective way for both teachers and students to communicate what is known (Gallas, 1995, 2003). Teachers gain important clues about how students construct personal meaning, and these clues then influence their future instruction.

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13-7 Using Technology to Assess Understanding

Technology-rich environments provide students with many additional ways to express their understanding to others. For example, as mentioned earlier, science notebooks kept on a computer can incorporate images as well as words. Students easily access websites to "cut and paste" pictures or other graphic materials that enhance their scientific explanations in their notebooks. They may take photos with their phones for inclusion in electronic science notebooks.

Even more dramatically, technology offers students the opportunity to design products that demonstrate what they know about a given topic. Almost daily, it seems, new software products are emerging that are designed to reveal students' understanding of a topic. Many students, particularly those who may have difficulty expressing themselves in typical oral or written forms or in traditional test formats, embrace technology-based assessments as a way to express themselves creatively. These activities are also a good way to challenge gifted and creative students to expand their horizons.

The possibilities for technology-supported assessment are endless, but in this section we will look at two specific tools: concept maps and electronic presentations.

13-5a Concept Maps

You may recall that in Chapter 2 Ms. Parker used a concept map to help develop and scaffold the complex understanding of the surface tension of water. This type of concept map, with arrows and circles, may be created by students as a form of assessment.

Think about how you might use concept maps for the sixth-grade unit on the moon described in Chapter 8. You might give students this assignment: "Placing the term *Moon* in the center of a concept map, demonstrate your understanding of how the moon shines and how it moves. The terms you may use include, but are not limited to, *Rotation*, *Revolution*, and *Reflection*."

Now, combine this with Web-based or application software that helps create the symbols in concept maps, and the students can easily be creative in expressing their understanding of certain features of the moon. Students can readily create the sort of concept map shown in Figure 13.1. Notice how the ovals relate to two different kinds of concepts about the moon and how the arrows demonstrate their linkage. This structural representation of

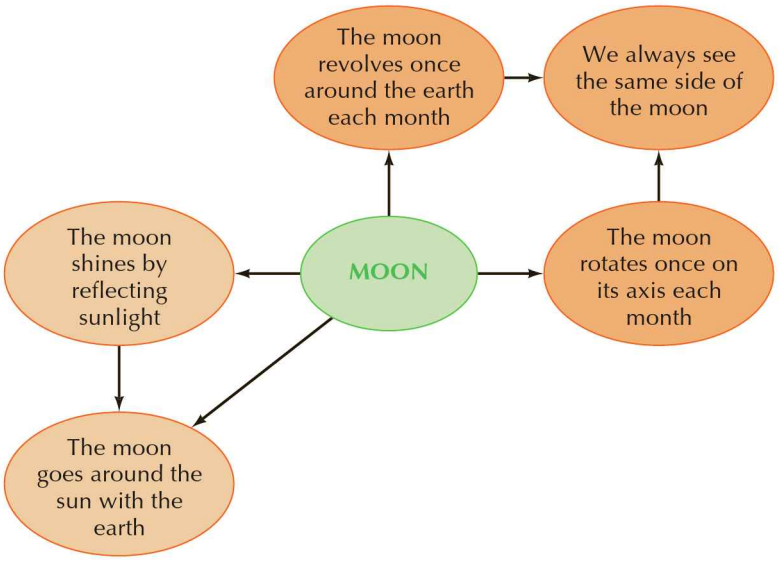

FIGURE 13.1 Sample concept map for a sixth-grade unit on the moon

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understanding gives students another way of expressing meaning. The more ways in which we ask students to demonstrate what they know, the more possibility there is for students to actively engage in thinking deeply about a concept.

Concept maps may be saved and developed further as students continue to build their knowledge. You can make a concept map assignment open-ended by asking students, for instance, to link "everything you have learned about the moon to the center circle." With current software, they can easily create links and arrows and build confidence in organizing information, understanding concepts, and expressing their thoughts. Remember, though, that just as a concept map shows what students know, misdirected links or wrong connections reveal what they don't understand. When using students' concept maps for assessment, you need a scoring rubric that details the accuracy of the links, the level of explanation, and the complexity of the concept (Stoddart et al., 2000).

13-4b Electronic Presentations

Another kind of software that allows students to express their understanding is *presentation software*. This general category includes various programs that combine text, graphics, video, and sound in a single presentation. Microsoft's PowerPoint, widely used in business, is the most common example.

PowerPoint presentations consist of a series of "slides" that appear on the computer screen and can be projected onto a larger screen. You have seen this used often by teachers and may have had to create your own as an assessment tool. Teachers can provide rubrics to explain their expectations and then ask students to create their own presentations. For a PowerPoint presentation on earthworms, the class might be asked to design four slides that explain how earthworms move, what they eat, what their habitat is like, and how they respond to stimuli. One slide might display a drawing of an earthworm along with a short, descriptive passage of text. Students might design this slide so that, with the click of a mouse, the earthworm would appear to move slowly across the screen, accompanied by a recording of a student's voice offering observations about the movement. Creating such a personal design package and presenting it to the class is an excellent way for students to use computer technology for assessment.

As with all other types of nontraditional performance-based tasks, technology design efforts must be evaluated according to an assessment checklist and rubric. If the students in Ms. Travis's fourth-grade class were asked to work in groups to design a PowerPoint presentation to compare series and parallel circuits, the following assessment checklist might guide them:

- Does your presentation state the goal of the program?
- Does your presentation include the materials that make up electric circuits?
- Does your presentation show drawings of the two types of circuits?
- Does your presentation offer real-life examples in which both types of circuits are used?
- Does your presentation analyze the strengths of both types of circuits?

Regardless of the form your students' presentations take, the students themselves must be aware of the criteria for success if you are using their performances to measure the level of their understanding. Remember, the more varied the types of assessment you use, the more authentic information you will gain about students' understandings.

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13-8 Multiple Types of Performances

The options described so far in this chapter, including science writing assignments, notebooks, portfolios, and presentations, are all useful methods for performance assessment. That is, they all can engage students in carrying out an assessment task that is relevant to the instructional context. These methods are far from the only possibilities, however. The following stories describe different ways in which students exhibit their understanding through performance.

13-4b Third Graders Enact the Water Cycle

In Ms. Nelson's third-grade classroom, the students have been exploring the water cycle and weather. On several days they have gone outside to observe the sky and make drawings of different clouds. They have been heating water and watching what happens. One day, Ms. Nelson places a pan of ice cubes over a pot with steam rising from it, and the students observe water droplets forming on the bottom of the pan. As these water droplets grow in size, they become so heavy that they fall back into the pot.

Many science ideas have emerged during the students' investigations of what happens to water when it is heated, what happens to steam when it is cooled, and the connections between their classroom models and the weather outside:

- When water is heated, it changes into steam.
- Steam rising from the pot looks like smoke.
- When steam is cooled, it turns back to water.
- The water falls back to the pot, filling it up again.
- The water becomes steam again when it is heated.
- When I see my breath in the winter, it is like a cloud.
- Steam is really a gas called water vapor.

Toward the end of a week of exploration, Ms. Nelson introduces three terms: *evaporation, condensation,* and *precipitation*. She asks the students to think about how these terms describe some of the big ideas they have gathered.

The students have heard the term *evaporation* often. They know that the word applies to what happened when they washed the blackboard and the water seemed to disappear. Also, they have heard the term *precipitation* in weather reports, so they can connect it with their water droplets falling back into the pot. But they are not sure about the term *condensation*.

At this point, Ms. Nelson draws a chart with arrows depicting water evaporating, becoming part of the clouds, and then precipitating back down to the earth. The students reason that condensation must be the process of the gas's turning back into the water droplets. Ms. Nelson is impressed with their reasoning.

After some time, Ms. Nelson asks, "How shall we express what we know about the water cycle and weather?" The students come up with a variety of ideas:

Write a poem	Write a song
Do a dance	Write a story

Ms. Nelson asks, "What should all of our water cycle and weather projects have in common?" The students decide that their projects have to explain their understanding of *all* the big ideas about the water cycle they have listed that week.

Now Ms. Nelson guides the students to form groups that reflect their various talents and interests. Class time is set aside for group meetings, and resources are made available. The dance group, for example, needs a tape recorder; the art group needs brown butcher paper, pencils, and colored markers.

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Eventually, all of the groups present their projects to the class. The song group sings a song they have composed about the water cycle, with instrumental accompaniment provided by one of the members who has brought in his guitar. The members of the dance group, except for the student playing the role of the sun, mime raindrops in the water cycle. They start out crouched on the floor like water particles, reach up to the sky like gas particles, shiver and huddle together to form a cloud, and gracefully fall down to the ground as rain—all to the background music of "Raindrops Keep Falling on My Head." Some students have opted to write personal water cycle stories, which they read to the class. One student has imagined that she is a drop in the water cycle, and she describes her journey through evaporation, condensation, and precipitation.

In Ms. Nelson's class, all of the students have become engaged in the experience, thought deeply about it, made personal choices, and reflected a high level of understanding about the water cycle. The multiple assessment modes have allowed them to use various talents and means of presentation to express what they know. This is one way to implement what Brooks and Brooks (2001) refer to as "assessment in service to the learner."

You may remember that we explored stations in a "science circus" in Chapter 3 and then again in Chapter 11 when students participated in a "magnet circus." These activities also lend themselves to performance assessment as students respond to tasks at each station to measure their understanding of a concept. In the next story, second graders respond to questions about states of matter on a station-to-station assessment task.

13-4a Second Graders Do a Station Assessment for a Unit on Matter

station assessment
An assessment activity in which workstations are set up around the room to create a genuine context for the students to perform tasks. The students typically use an answer sheet to respond to the questions at each station. Each workstation assesses a different aspect of the science unit.

Setting up workstations around the classroom is an assessment format often called a **station assessment**. The students use an answer sheet to respond to the questions at each assessment station. You must be sure that these workstations create a genuine context for the students to perform a task. Each station must challenge them to create meaning based on their prior knowledge and on the experiences in which they were engaged during their science study.

Consider this station assessment developed by second-grade teachers for a science unit on matter. Their school is in the Northeast, and it has been a snowy winter. The children will visit three stations.

At Station 1 they find a plastic bag of air, a plastic bag of water, and a plastic bag of ice. The children are encouraged to examine these bags but not to open them. The card on the table reads: *Look at the plastic bag of ice cubes, air, and water. In what ways are they the same? In what ways are they different?*

At Station 2 are two identical glasses of water. One is covered, the other uncovered. The card reads: *What do you think will happen to the water in the glass with no cover if we leave it out on a sunny day?*

At Station 3, the students discover sheets of paper for them to take. Each sheet has three boxed pictures on it. The pictures represent different stages of a snowman melting. The card reads: *Take one sheet and cut out the pictures. Paste the pictures in order. What is happening in each picture?*

When the second-grade teachers designed these stations, they knew they also needed an assessment checklist and rubric, so they developed the one shown in Figure 13.2. After using the assessment in their classes, all of the teachers felt it had worked well. For the students, it was an important experience. For the teachers, the tallies of the class's performance led to a useful evaluation of the science lessons. The results of this assessment helped the teachers modify the curriculum and instruction to meet the students' needs.

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The following hands-on assessment of the second-grade unit on matter will provide us with a better understanding of what students know and are able to do as a result of their experiences with the matter unit.

1. Stations 1 and 2 invite observation, comparing, classifying, and describing.
2. Station 2 asks students to predict an outcome that they cannot observe at the moment.
3. Station 3 asks students to place events in their proper time sequence and describe the event in each picture.

Scoring Rubric—Matter Assessment

	YES	NO
1. Uses scientific terms such as: *solid, liquid, gas, evaporation*		
2. Accurately describes the water.		
3. Accurately describes the ice.		
4. Accurately describes the air.		
5. Makes reasonable predictions about the glass of water that is uncovered: Water will get warm. Water will disappear.		
6. Correctly sequence events.		
7. Describes pictures accurately.		

The following categories reflect the number of "yes" checks:

Budding scientist	Scientist	Super scientist
2–3	4–6	all 7

FIGURE 13.2 Sample checklist and scoring rubric for a station assessment

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To develop station assessments, you need to do the following:

1. State the goal of the assessment.
2. Describe the format of the assessment tasks, making sure that they match the instructional activities.
3. Develop a scoring rubric for measuring student competence.
4. Evaluate the students' responses to the experience.

13-9 Assessing, Teaching, and Learning

If we engage students in meaningful science experiences that relate to real-world contexts, then we need to assess them with meaningful experiences that relate to real-world contexts. To put it another way, when we allow students to be active participants in their own learning, we should assess their understanding with tasks that actively demonstrate what they know and are able to do—tasks that match the instruction.

Assessment tasks are authentic when they ask students to apply their science knowledge and reasoning to situations and contexts that are found in

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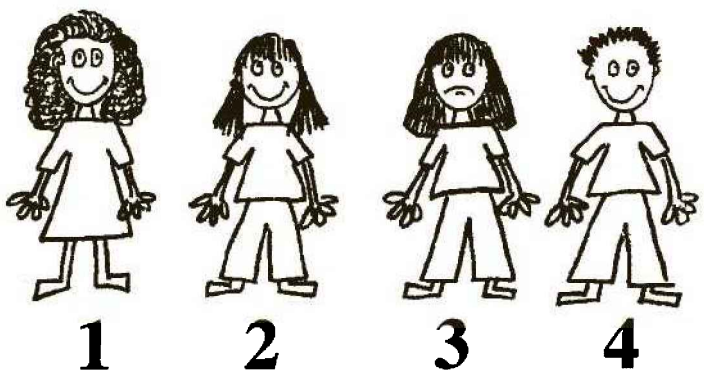
the real world. This enhances the real-world context of science instruction. This chapter has advocated extensive and multiple means of performance assessment, including problem solving, creative writing, drawing, drama, technology applications, and other original forms of presentation.

After contemplating all these performance-based assessment measures, you may wonder whether there aren't any traditional paper-and-pencil tests that would be useful. You can indeed use paper-and-pencil tests, with multiple-choice or fill-in questions, to assess your students' familiarity with terminology and their recall of particular bits of science knowledge. Also, paper-and-pencil assessments have been constructed to measure students' science process skills (Smith & Welliver, 1990). In the example shown in Figure 13.3, developed for fourth graders, the test questions were matched to specific science process skills. Looking at the figure, you should be able to identify questions that relate to the skills of observation, inference, comparing, contrasting, and so on. But notice that although each question engages the student in using a process skill, there is no apparent reason to do so. There is no real-world context. Hence, tests of this type may have limited usefulness for teachers who want an active demonstration of their students' understanding.

Since educational data profoundly influence the lives of students, the design of assessments requires careful consideration. The drive to support authentic instruction with authentic assessment is a reaction to the many paper-and-pencil standardized tests that, because they are administered on a very large scale, lack much of the authenticity of performance-based assessments. Often, teachers use these tests as guides for teaching their unit. This "teaching to the test" has been prompted by the high stakes connected to student performance. This does science teaching and the students a disservice. If we authentically teach and authentically assess, then the depth of understanding that develops will be more than sufficient for adequate performance on the standardized tests.

FIGURE 13.3 A paper-and-pencil test that invites students to use process skills

Look carefully at these students.



4. Which of the following statements about these students is correct?
   A. Students 1, 2 and 3 all have long hair
   B. Students 2, 3 and 4 all have long pants
   C. Students 1, 2 and 4 are all smiling
   * D. All of the answers A, B and C are correct

5. A. One student has short hair
   B. One student is wearing a dress
   C. One student is not smiling
   * D. All of the answers, A, B and C are correct

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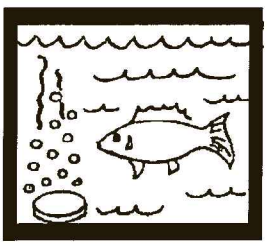
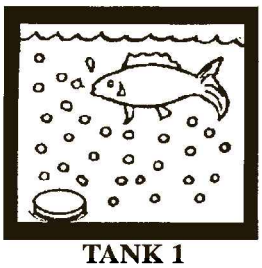
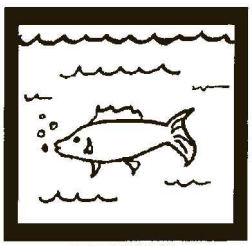
FIGURE 13.3 (*continued*)



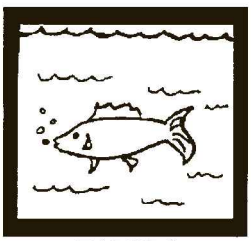
TANK 1
Guppy swimming -- Student drops an alka-seltzer tablet in the tank. The bubbles are carbon dioxide.



TANK 1
After one minute, guppy stopped swimming and had trouble breathing.



TANK 2
Guppy swimming -- Plain water.



TANK 2
Guppy swimming -- Plain water after one minute.

8. Which sentence would best describe what effect alka-seltzer has on a guppy?
   * A. Guppies may not be able to survive long when carbon dioxide is in the water.
   B. Guppies become active when carbon dioxide is in the water.
   C. Guppies show no change in behavior when carbon dioxide is in the water.
   D. All of the answers A, B and C are correct.

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As you have seen throughout this chapter, a good assessment task fits into the science experience and is a good instructional task as well. The students do not feel judged or threatened, and the teacher discovers what they know and understand about a science concept. Understanding what your students know about a topic will then influence your science instruction. Hence, assessment and instruction are interactive.

Remember that your class will probably include diverse groups of students with different learning styles and multiple ways of communicating their ideas. If you vary the types of assessments you employ, you create a more equitable learning environment. The chances are that by using multiple modes of assessment, you will find a match for the mode of expression that each student feels most comfortable with. When you use a single assessment approach, you place students who are not comfortable with that selected way of expressing themselves—or students who have disabilities in a specific mode of communication—at an unfair disadvantage.

Remember that assessment is ongoing. It is embedded in all the work you do with your students. Keep asking yourself questions like these:

- Who are my students?
- How can I learn about what they understand?
- In what ways do they express themselves?

Assessing your students' learning can also lead you toward an assessment of your efforts as a science teacher. The next chapter will discuss how you can reflect on your own teaching as you engage students in science.

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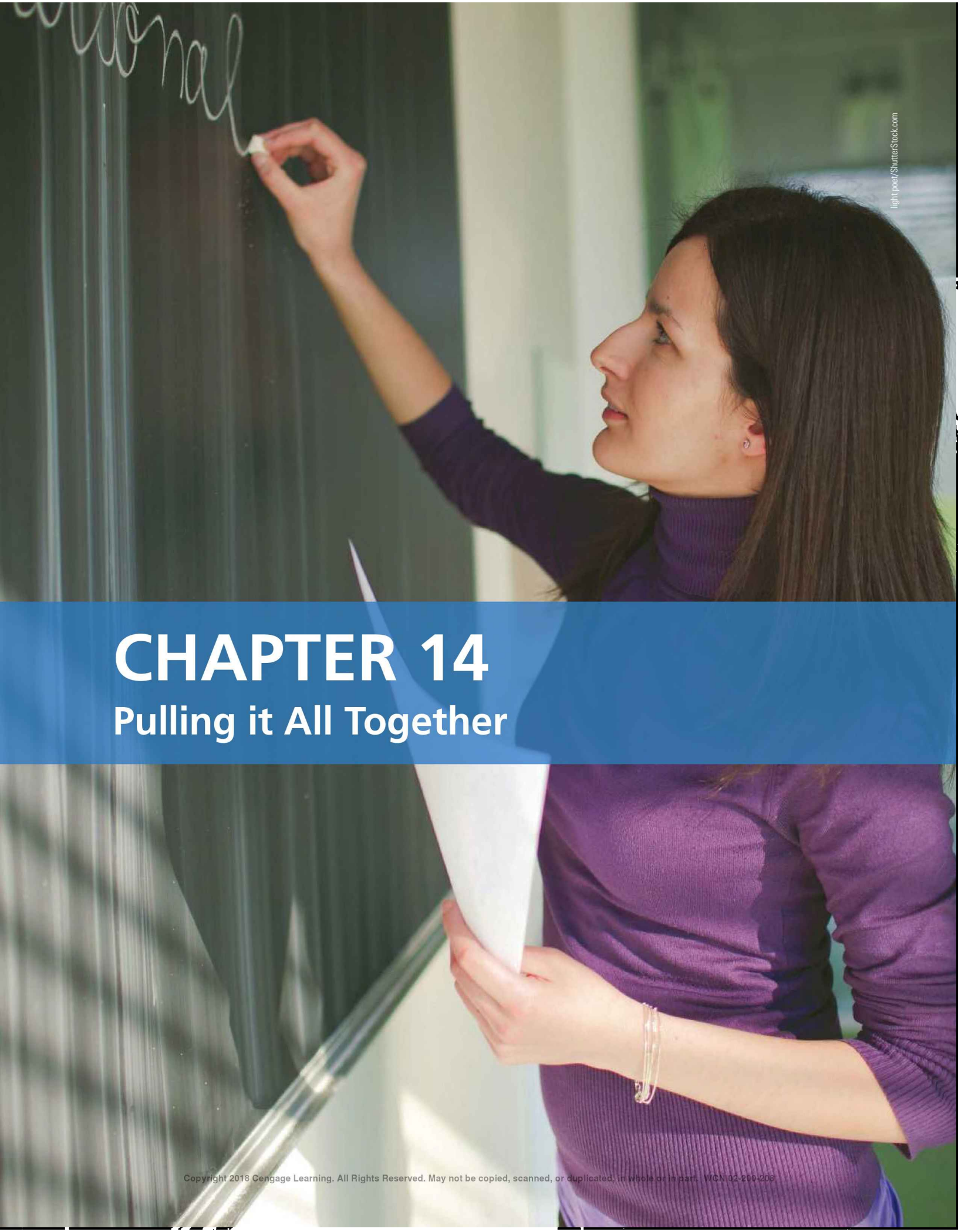

light poet/ShutterStock.com

CHAPTER 14
Pulling it All Together

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 14-1 Assess your own scientific self.
- 14-2 Develop a personal science teaching philosophy.
- 14-3 Examine professional development options.
- 14-4 Engage in self-evaluation.
- 14-5 Continue your science autobiography.

Reflection

To Think About:

- Have you begun to make observations of the natural world in ways that are new to you?
- Have you been exploring scientific websites?
- Have you examined one or more science lessons?
- Have you discovered your scientific self?

We close *Science Stories* where we began—with our own scientific selves. You may wonder why I return so regularly to our scientific selves. It is because we do our best science teaching when we are a *model* to our students of curiosity and excitement about how the natural world works.

14-1 Your Scientific Self

You would like, I'm sure, to show your students what it looks like to wonder, to get messy, to explore nature, to yearn to find out about the natural world, and to be thrilled at the prospect of experimenting. In order to convey these feelings to your students, you need to feel them authentically inside yourself.

My own feelings about science are not static. My descriptions of science and scientific study change as I grow and develop, and I am always adding to my list. I invite you to develop your own descriptions of science as you have opportunities to do science with students. The following list contains statements that are true for me at different times. They change as I change, as I interact with nature and with students.

- Science is a way of exploring nature.
- Science is both a method and a set of ideas.
- Science is a subject in which you expect the unexpected.
- Science is an area of study that can be frustrating.
- Teaching science can help reveal your students' thinking.
- Science is a dynamic area of study, ever changing, always revealing new evidence, and its practitioners are always revising their ideas based on new evidence.
- Science is a joyous activity when shared with students.
- Science is not about knowing but about trying to find out.

Which of these statements do you agree with now? Have your ideas about science changed as you read this book? What descriptions can you add?

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A large part of your journey toward becoming a successful science teacher involves locating your scientific self and becoming comfortable with it. Find ways to explore nature and write about it in a science journal; think about the characteristics of exploration; and come up with *your own* ideas and test them. Remember that we use scientific skills in our daily life, so look for experimentation in everyday places. Watch for opportunities to observe, infer, predict, classify, and investigate. Do research and gather evidence, for example, for global climate change. Engage in arguing from evidence. Some adults experiment in the kitchen or the garage or the garden. Ever curious about your environment, take these multiple opportunities to ask yourself:

- Where is "nature"?
- What do I notice?
- What do I wonder about?

Write down your thoughts, and then share them with your students.

When you find your scientific self, you can no longer view science as just a subject taught in school. As you open your eyes to nature, you feel a sense of confidence about exploring the scientific reasons for natural events. Look in your newspaper for items of interest that relate to scientific discovery; share these with your students and encourage them to do the same. Ask yourself: What contemporary scientific issues especially engage me? Are they environmental issues? Or do they relate to health and nutrition? At this writing, I am struck by the shrinking ice sheet on Antarctica. My good friend does research there every year and sends me photographs of the shrinking habitat for the Adélie Penguins that she studies. On my Twitter account, I wrote briefly about how unpredictable the ocean currents and prevailing winds have become since the rise of ocean temperatures across the world. We are, indeed, surrounded by science stories.

Similarly, take time to visit local community resources. Look around for zoos, museums, botanical gardens, science and technology centers, bird sanctuaries, and other informal science learning sites. Watch for dandelions in the cracks in the sidewalk. Being alert to all these opportunities to explore the natural world will help you become a successful science teacher as well as a lifelong science learner.

14-2 Developing a Personal Philosophy

Locating your scientific self takes time, and it often requires that you reflect on nature and the way nature presents itself in your world (Photo 14.1). This reflection is an *active process* involving deliberative thinking, not passive musing. Further, it often leads to additional action to consolidate your understanding. When you reflect on an aspect of nature, you may be impelled to ask questions about it, to learn more about it, and to make sense of it. The bird story early in this book—the entries from my science journal about the birds in the tree behind my house—is an example of how reflection stimulates further learning.

Being an effective teacher similarly requires frequent reflections on your students' thinking and on your own teaching practices. These reflections, too, lead to further action. Reflecting on how your students are responding to a lesson may require you to alter your lesson plan and change the course of subsequent lessons. On a larger scale, being reflective about your teaching practice will prompt you to seek out additional means for professional development, such as workshops and contacts with other teachers.

As you begin your teaching career and engage students in scientific experiences, you will develop your own personal philosophy of teaching. By thinking about what you firmly believe and what you remain unsure about, you can promote your development as a teacher.

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PHOTO 14.1 The teacher explores a natural environment with her students.

One useful technique is to develop a personal philosophy statement. It should contain your thoughts and feelings and indicate their connection to your actions as a teacher. As one such exercise, try completing the following statements (adapted from Kochendorfer, 1994):

- I am the kind of science teacher who thinks that . . .
- When I do science with students, I feel . . .
- The science experiences that I believe are most worthwhile include . . .

If you can complete those sentences, you already have a rough draft of your philosophy statement. But it undoubtedly will change over time. Consider engaging in this sort of reflection during every school year, and keep track of your philosophy statements. You may be amazed at your own growth as a scientist and as a teacher.

14-3 Professional Development

professional development
The process by which teachers strive to improve their work as teachers in order to grow in their profession. It is generally based on inquiry into their own teaching practices, active engagement in their own research, and teacher workshops and courses.

Professional development is the process by which teachers strive to improve their work and to grow in their profession. It is education intended to refine your skills, keep you updated on new developments, or engage you in specific projects related to curriculum and its implementation. Your personal professional development is based, most of all, on inquiry into your own teaching—inquiry that leads to research and action. Reflection is part of that inquiry process, but there are numerous additional activities and resources to which you can turn. Many of them involve interactions with your professional colleagues, either within your school or in more extended networks.

14-3a Networking in the Profession

As you teach science, you will have many opportunities to interact with colleagues and join networks of teachers whose personal philosophy about teaching and learning is similar to your own. Local teacher centers and science organizations offer workshops and courses that create such networking opportunities for you.

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Liquorice Legs/Shutterstock.com

PHOTO 14.2 Meetings and discussions with colleagues play a major role in a teacher's professional development.

Why should you spend time on professional networking? Research tells us that teachers who engage in professional communication with colleagues refine their practice throughout their careers (Darling-Hammond, 1998). (See Photo 14.2.) Networking activities can include experiential learning—for example, working with colleagues on concrete tasks, such as developing a science station assessment. They can also include working with a mentor teacher in your own school, observing an exemplary teacher, and attending teacher discussion groups centered on teaching practice.

Look for such opportunities in your own school and district. Be alert for opportunities to attend science teaching workshops. Inquire whether your school or district will offer funding for you to attend national or regional conferences. Research online courses or workshops that refine your own science teaching and content understanding.

As a first step, you can join your state science teachers' association and the National Science Teachers Association (NSTA). Membership in the NSTA includes a subscription to *Science and Children* or *Science Scope*, which are journals devoted to science teaching.

14-3b Promotion and Certification Requirements

Increasingly, teachers are being required to show evidence of their professional development in order to earn promotions or even to have their teaching certificates renewed. Since requirements vary from state to state, you should explore the criteria in your own locale.

On the national level, certification is being offered by the National Board for Professional Teaching Standards (NBPTS). Established in 1987, the NBPTS is a nonprofit organization governed by a board of directors that includes classroom teachers as well as school board leaders, former governors, and business and community leaders. The mission of the NBPTS is to establish high and rigorous standards for what accomplished teachers should know and be able to do and to operate a national, voluntary system for assessing and certifying teachers who meet these standards. By 2015, there were more than 112,000 National Board–certified

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teachers (NBPTS, 2015). For elementary and middle school teachers, there are generalist certification standards for teaching students in early childhood (ages 3–8) and middle childhood (ages 7–12). For science teaching in particular, there are certificates for teaching students in early adolescence (ages 11–15) and adolescence through young adulthood (ages 14–18+). Some elementary school teachers become so interested in engaging students in science that they return to school part-time and take more science courses for higher-level certifications.

The five core propositions around which the National Board has organized its standards are the following:

1. Teachers are committed to students and their learning.
2. Teachers know the subjects they teach and how to teach those subjects to students.
3. Teachers are responsible for managing and monitoring student learning.
4. Teachers think systemically about their practice and learn from experience.
5. Teachers are members of learning communities.

Advocates of the National Board believe that offering professional credentials brings prestige to the teaching profession, and they hope that schools and school districts will see NBPTS certification as a valuable teaching qualification. You may want to visit the NBPTS website and explore the requirements for certification. You must have been teaching for a minimum of three years, have had a valid teaching license for all three years, and have completed your baccalaureate degree to be eligible to take the series of assessments that lead to an NBPTS certificate.

14-3b Further Means of Professional Development

Besides networking with colleagues and fulfilling state and local requirements for advancement in the field, there are many other ways that you can promote your own professional development as an elementary or middle school science teacher. Here are some ideas:

- Do research on science topics. If there is a topic that you wish you knew more about, turn to good search engines to research it. Be sure to gain confidence in the science content areas that you will be exploring with your students.
- For exemplary science instructional materials, refer to the curriculum guides listed on the MindTap for this book in addition to other resources mentioned throughout this book. Great Explorations in Math and Science® (GEMS) is a wonderful source of pre-K–8 curriculum materials.
- Trust your own judgment. If you come across a scientific investigation that does not appeal to you, most likely it won't appeal to your students either.
- Keep a science journal for both in-class and outside-of-class science activities.
- Do your own research on what is happening in your classroom. **Action research**, also known as **classroom research** or **teacher research**, involves research projects in which classroom teachers explore some area of their teaching or some aspect of the students' learning. For example, they may study how their students are experiencing a science unit, lesson, or activity. The goal of action research is to improve your own or a colleague's teaching. Sometimes an action research project is a questionnaire you distribute to students to learn what they thought about an investigation or a

action research (also called classroom research or teacher research)
Refers to research projects in which classroom teachers explore some area of their teaching or some aspect of the students' learning with the goal of improving their own or a colleague's teaching.

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1. How am I providing opportunities for students to explore nature?
2. Am I allowing ample time for students to complete their investigations?
3. Do the students express their own ideas? Why not?
4. Do I encourage the students to ask questions? How?
5. How am I a coach or facilitator for the science experience?
6. What happens when the students ask questions that we do not have time to explore?
7. How do I use technology for science teaching and learning?
8. How good am I at letting go of my plan if necessary?
9. What assessment techniques am I using?
10. Am I having a good time doing science with my students? What is the best part?

FIGURE 14.1 A checklist for self-evaluation

Professional Resource Download

unit. Sometimes the research design is more extended, depending on what you want to find out. Doing research in your own classroom is not complicated and can reap many rewards.

- Join a science teacher chat room or add regular comments to a blog. Reading other teachers' stories and commenting on them can bring you new ideas as well as a sense of community. The NSTA website can network you to discussion groups.

14-4 How Am I Doing? A Guide to Self-Evaluation

Science teaching, like all other teaching, is a commitment to becoming a lifelong learner. As you reflect on what you have learned and how you teach, the checklist in Figure 14.1 may help you evaluate your professional growth. Revisit the table's questions from time to time.

If you are unsure of your progress in any of the areas listed in Figure 14.1, ask a colleague to make a video as you teach. Videos are often useful as personal guides for developing professionally. Use the checklist to review the video and assess your own progress.

But don't let the checklist—or any other teaching guidelines—intimidate you. Go easy on yourself at first. Be prepared to fumble now and again. You are traveling in what may often be uncharted territory. Do not be discouraged—science takes time.

14-5 Looking Back to Look Ahead: A New Chapter in Your Science Autobiography

Science Stories has been an attempt to have a conversation with you about science teaching and learning—about yourself as a science learner and a science teacher. As one of the goals for the book, I hoped to engage you in the stories of real students and real teachers who were learning science together and separately. To encourage your professional growth, I've also tried to connect you with some of the research that has influenced this way of doing science with

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students. In Chapter 11, I examined connections to other disciplines and encourage you to seek those connections.

Science teaching needs to encourage, invite, engage, excite, interrogate, and challenge. I also like to say that it should shine like a beacon, signaling that science is truly for everyone. Science teaching can make connections to students' lived experiences and help them to frame their own questions about natural phenomena as a way of making meaning of their world. I always hope that students will take ownership of their own knowledge and gain autonomy as they seek their own answers. But everything I hope for the students I also hope for you, their science teacher.

When you have your own classroom, take a moment after the first hectic months and draw a picture of yourself as you are teaching a "typical" science lesson. Drawing skill is not important—just try to portray what is going on. Place a caption under your drawing and have a look at it. You can interrogate your drawing by asking: What am I doing? What are the students doing? What is my position in the room? How confident do I feel in my science teaching? This exercise will help you continue to develop as a science teacher.

Right now, as a result of your own journey toward science teaching, you may be ready to begin the next chapter of your science autobiography. You may even want to start writing your own science stories. One teacher summarized her feelings about doing science with students in a poem; the first letters of the lines spell out the word *inquiry:*

Investigate and you will find,
New information of some kind,
Question all your observations,
Understand through your explanations,
Integrate what you have discovered,
Reflect and share what you have uncovered.
You are doing science! (Carol Federico, 2002)

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Glossary

A

action research Refers to research projects in which classroom teachers explore some area of their teaching or some aspect of the students' learning with the goal of improving their own or a colleague's teaching. Also called *classroom research* or *teacher research*.

alternative conception An idea that is not scientifically accurate but represents a step toward full understanding of a concept.

angiosperm One that produces flowers that eventually form fruits with seeds. Also called *seed plant*.

Animalia (animals) The scientific name for the animal kingdom. It is commonly divided into two broad groups: animals with backbones and animals without backbones.

aphelion The point in a planet's orbit when it is farthest from the sun.

assistive technology (AT) Devices or services that promote greater independence for people with disabilities by enabling them to perform tasks that were formerly difficult or impossible.

asteroid A tiny chunk of planet-like material that moves around the sun. Between Mars and Jupiter, there is a belt of several thousand asteroids of different sizes.

atom The smallest part of an element that retains the properties of that element. There are ninety-two different kinds of atoms found naturally on earth. The atoms of each element are exactly the same as one another and different from those of any other element.

authentic assessment *See* Performance assessment.

B

big idea An overarching concept that is the organizing principle behind a number of discrete scientific facts.

blog An online journal (short for "weblog"); in education, blogs are personal journals in which students and teachers post their thoughts and observations and others can respond.

buoyancy The lifting force that water exerts on objects. All objects appear to be lighter in water because of the buoyancy of water.

C

carbon-14 dating The process of determining the amount of the naturally occurring radioactive isotope, carbon-14, found in old carbon-bearing materials. When compared with the amount of carbon-14 naturally occurring in the atmosphere, the approximate age of the material is determined. Based on fixed rates of radioactive decay. Accurate to 60,000 years.

chemical change A change in the chemical properties of a substance, that is, in the composition of the substance and the way it behaves with other substances; also called a *chemical reaction*.

chlorophyll The substance in leaves that allows the chemical reaction of photosynthesis to take place and that gives leaves their green color.

circulatory system The system that maintains a continuous flow of blood around the body. The main parts of this system are the heart, arteries, veins, and capillaries.

classifying Sorting objects or ideas into groups on the basis of similar properties.

classroom research *See* Action research.

climate The average pattern of weather for a particular region, measured over a long period of time.

comparing and contrasting Discovering similarities and differences among objects or events.

compound A combination of two or more elements in a definite proportion. For example, water is H_2O—two parts hydrogen to one part oxygen.

concept map A diagram for developing an understanding of relationships between ideas. A concept map consists of circles or boxes that are called cells and that contain an idea, a selected term, or a question. The cells are linked with labeled lines and/or directional arrows that explain the relationships.

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constant An experimental condition that remains the same throughout a scientific investigation.

constructivism A family of theories about knowledge and learning whose basic tenet is that all knowledge is constructed by synthesizing new ideas with what we have previously come to know. This means that knowledge is not passively received. Rather, knowledge is actively built up by the learner as he or she experiences the world.

cooperative learning An instructional approach in which students work together in groups to accomplish shared learning goals.

cooperative learning group An arrangement in which a group of students, usually of mixed ability, gender, and ethnicity, work toward the common goal of promoting each other's and the group's success.

cotyledon The part of the seed that has food stored in it for the tiny plant. Also called the *seed leaf.*

crosscutting concepts (CCs) A way of linking and thinking about the disciplinary core ideas in science. These concepts help students develop a coherent and scientifically based view of the world.

current *See* Electric current.

curriculum A plan of studies that includes the ways in which the instructional content is organized and presented at each grade level.

D

density Mathematically defined as the mass of an object divided by its volume (expressed numerically in grams per cubic centimeter). Roughly, density can be conceived as how closely packed together the particles of an object are or as the relative number of particles that can fit into a given amount of space.

design challenge In design technology, a specific problem that students are asked to solve by designing and constructing a product or an optimal solution.

design technology (engineering design) The process by which solutions to problems are arrived at through planning and trying out options in order to optimize the final product or idea. For students, the design process is iterative and typically involves solving a problem by constructing a product that meets a set of established criteria, called specifications.

dialog poem A poem written in two or more voices that represent multiple perspectives on a topic or a concept. May be used to assess understanding of a science concept.

dicot Seed-producing plant with two seed leaves, or cotyledons. Dicots include most flowers, vegetable shrubs, bean plants, and flowering trees.

differentiating instruction Adapting instructional techniques to suit the needs of specific children or groups of children in a classroom.

digestive system The body system that breaks down food into a form that can be absorbed and used by the body.

digital divide The gap between those with easy access to digital technologies and those without.

disciplinary core ideas (DCIs) Science concepts identified by NGSS that have broad importance across several branches of science addressing four domains: life science; physical science; earth and space science; and engineering, technology, and applications of science. These concepts are represented by learning progressions as students' ideas mature over time.

discovery learning A phrase popularized by learning theorist Jerome Bruner, who suggested that, at any given stage of cognitive development, teaching should proceed in a way that allows children to discover ideas for themselves.

dissolve When solid particles (such as salt) are broken down into invisible particles when placed in a solvent such as water. The solid particles seem to disappear because they are present in molecular or ionic form.

E

earthquake A sudden slippage of rock.

ecosystem A natural space in which all the living things (biotic factors) function together with all of the nonliving things (abiotic factors) in a specific environment.

electric circuit A pathway for an electric current. A circuit requires some source of electrical power, such as a battery or generator, and a material through which electrons can travel, such as copper wire. In elementary school science, circuits usually include some simple appliance that uses electricity, like a light bulb or a bell.

electric current A flow or motion of electrons. Electric currents in wires are caused by electrons moving along the wire.

electricity A form of energy produced by a flow of electrons.

electron A negatively charged particle found in the atoms of all elements. Electrons revolve around the nucleus of the atom in different orbitals or "shells"; each

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shell represents a distinct energy level. Each electron is thought to be a particle of negative electricity.

electron cloud A term for the general area occupied by each "shell" or energy level where electrons orbit the nucleus of an atom. The metaphor of a "cloud" emphasizes the fact that we cannot know exactly where an electron is at a particular time; we just know that it is somewhere within that general area.

element A substance made up of only one type of material. The simplest form of matter, elements are the building blocks of all other substances. There are ninety-two naturally occurring elements in the universe and about fifteen others that have been produced by scientists in laboratories. Iron, nickel, gold, silver, oxygen, hydrogen, helium, carbon, and mercury are all elements.

ellipse An oval shape with no center but with two points of reference called *foci*. Planets travel in elliptical orbits around the sun, which is located at one of the foci of the orbits.

emerging relevance A perception by students that questions or ideas arising from an investigation have personal significance to them. The key part of this concept is that certain matters become relevant to students as they engage in learning activities. By helping them explore these emerging questions and ideas, teachers can help students construct their own meaning.

energy The ability to do work.

evaluation The process of examining all the data gathered from various types of assessments to judge a student's or a group's achievement in a learning area.

evidence In science, evidence refers to the total amount of information that is used to demonstrate or determine the truth of an assertion, such as a fact or a theory.

F

fair test An investigation in which all the experimental conditions remain the same (constant) except for the one being tested (the variable).

family science night A community-involvement activity in which students bring a significant adult or adults to the school to participate in inquiry-based science activities typically set up at stations in a large classroom or in the school cafeteria.

faults Large cracks or breaks in the earth's crustal plates. Earthquakes are most common in areas where there are major faults.

focus One of two points (foci) used to construct an ellipse.

force A physical agency (such as a push or a pull) that tends to cause a change in the position or motion of an object.

formal science curriculum The explicit statement by a school or a school district of the science topics and methodologies to be implemented at each grade level.

formative assessment Assessment that gauges students' understanding of a particular topic in a unit in order to judge their progress and adjust the rest of the instruction accordingly.

fossil fuels Fuels such as oil, gas, and coal that derive from the remains of plants and animals that lived long ago.

fruit A ripened ovary of a seed plant; a container for the plant's seeds.

Fungi A kingdom of living things containing tiny plantlike organisms. Fungi do not have chlorophyll and cannot make their own food. Fungi include molds, mildews, yeast, and mushrooms.

G

gas A state of matter that has no definite shape or size. When a gas is poured into a container, it spreads out until it has the same size as the container and takes the shape of the container.

germination The process by which a seed sprouts and begins to grow into a new plant.

graduated cylinder A device used for measuring liquid volume. In essence, it is a scientific measuring cup—a glass or plastic cylinder calibrated in milliliters.

gravitation The attraction of any two objects that have mass. According to the law of gravitation, every body in the universe attracts every other body with a force that increases when the masses of the objects increase and decreases as the objects move farther away from each other.

green science The branch of environmental studies that includes the study of alternative and renewable energy, food webs, conservation, resource distribution, and the changes in world climate.

greenhouse gases Gases that reduce the amount of heat energy (infrared radiation) that is radiated back toward space when the sun's energy enters the atmosphere and strikes the earth. These gases include carbon dioxide, methane, and nitrous oxide. Many greenhouse gases occur naturally, but they may also be produced by industrial processes. Excess greenhouse gases in the atmosphere can cause average temperatures to climb over time.

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H

high tide High level of ocean waters, when the waters reach farthest onto land. On the side of the earth facing the moon, high tide occurs because the waters bulge out from the moon's gravitational pull. At the same time, on the opposite side of the earth, there is also a high tide because the moon's gravitational force has pulled the solid earth as well, leaving the waters bulging out on that side.

hypothesis An inference or a guess that is tested through a planned investigation or experiment.

I

igneous rock Rock formed above or below the earth's surface when magma (below) or lava (above) cools and hardens.

inclusion model The practice of placing students with disabilities in regular classrooms to the greatest extent possible.

inertia The tendency of a body to continue with the same motion at the same speed or to remain at rest.

inference Reasonable explanation that we construct on the basis of our observations. Inferences sometimes lead us to set up further investigations.

informal science curriculum Science learning experiences that go beyond the formal science curriculum of the school or school district to include other topics and methodologies that connect to students' daily life outside the school. The topics might arise, for example, from spontaneous natural occurrences, local news events, or materials the students bring from home.

inquiry The type of exploration that lies at the heart of scientific activity. According to the 1996 *National Science Education Standards*, inquiry is "a multifaceted activity that involves making observations; posing questions; ... planning investigations; ... using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results" (National Research Council, 1996, p. 23).

invertebrate An animal without a backbone. Invertebrates are the most numerous of all animals.

ion A charged atom.

iterative process The act of repeating a process of design where the final result of one process or *iteration* is the starting point for the next iteration until an optimized solution or target goal is reached.

J

journal *See* Science journal.

K

kinetic energy The energy of motion; that is, the energy that an object has because it is moving.

kingdom The broadest division of classification of living things. There are five kingdoms of living organisms: Animalia, Plantae, Protista, Fungi, and Monera.

L

law of conservation of matter and energy The scientific law asserting that matter and energy can be changed into each other but cannot be created or destroyed.

learning cycle An approach to teaching science that typically includes five phases of science teaching and learning: engagement, exploration, explanation, elaboration, and evaluation.

learning progression In science, the sequence of ever-deepening concepts that result in the understanding of a core scientific idea that is basic to explaining how the natural world works. They are based in research on how people learn.

lesson In science instruction, the process of engaging students in a meaningful science experience and in reflections on the experience.

lesson plan A document describing a teacher's plans for a particular lesson, including the ideas presented in the lesson, the activities that students will engage in, and the ways in which the teacher will help students reflect on their experiences.

light A form of energy radiated by the sun and stars. Light is only the visible part of the electromagnetic spectrum, which also includes many types of electromagnetic waves that we cannot see.

liquid A state of matter with a definite size but no definite shape. A liquid takes the shape of its container.

low tide Low level of ocean waters that occurs because, as the waters bulge on two sides of the earth, the remaining waters flatten.

M

magnetism A force produced when an object exerts an attraction for materials made of certain metals, such as iron, steel, cobalt, and nickel.

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mass The amount of matter that is in an object, typically measured in grams and kilograms.

matter Anything that has mass and takes up space.

meaningful science experience An activity that engages students in some of the key science and engineering practices and the key process skills of science, such as observing and predicting, inferring and hypothesizing, manipulating objects, investigating, and imagining; that relates to the students' everyday lived experiences; and that stimulates the students to reflect on what they are exploring and come up with their own ideas.

measuring Determining distance, volume, mass, or time by using instruments that indicate these properties (such as centimeter sticks, graduated cylinders, scales, or stopwatches).

mediator A teaching role in which the teacher helps students to learn by reflecting their own ideas back to them and guiding them in sorting out the inconsistencies. As a mediator, the teacher helps students delve deeply into their thoughts and expand their own thinking about an idea.

meniscus Refers to the curve at the upper surface of a liquid in a cylindrical container, such as a graduated cylinder. The bottom of the curve in a concave meniscus (liquid surface caves downward) is where the liquid volume measurement is taken.

metacognition Self-monitoring, with the capacity to "know what you know" and what you do not yet understand.

metamorphic rock Rock transformed from igneous and sedimentary rocks that are pushed below the surface (by shifts in the earth's crust or by lava flows) and subjected to severe pressure and heat.

mixture Any combination of elements, compounds, or other mixtures. Because there are only ninety-two naturally occurring elements, most matter consists of either compounds or mixtures.

model A representation of a system or object: for example, a physical structure that imitates a smaller or larger structure, a mental construct that represents an object or process, or a computer program that parallels the workings of a larger system.

molecule The smallest part of a compound that still has the properties of that compound. Molecules are made up of atoms.

Monera (monerans) A kingdom of living things consisting of bacteria, tiny organisms that do not have chlorophyll and cannot make their own food. All bacteria are made up of just one cell. Blue-green algae are also a part of the Monera kingdom.

monocot A type of seed-producing plant with just one cotyledon or seed leaf—for example, lilies, tulips, irises, onions, and grasses and grains. Also called *monocotyledon plants*.

N

nanoscale science Inquiry-based activities designed to help middle and high school students explore the unique properties and behaviors of materials on the scale of an atom or a molecule.

nervous system The body's internal communications network, including the brain, spinal cord, and nerves.

neutron A particle with no electrical charge found in the nucleus of an atom.

notebook *See* Science notebook.

O

observation Perception of an object or an event, using as many senses as possible.

open-ended questions Questions that lead to multiple answers. They are especially important because they help students think critically about their science experiences.

orbit The path of one heavenly body as it travels around another heavenly body.

P

parallel circuit An electric circuit in which each device has a separate pathway, its own separate branch of the circuit.

performance assessment A process of judging how well students execute a task as part of solving a problem in a larger context. Often the execution of the task involves a type of student performance. Also called *authentic assessment*.

perihelion The point in a planet's orbit when it is closest to the sun.

pH Measure of the acidity or alkalinity of a solution.

phases of the moon The various aspects of the moon as seen from Earth, such as the full moon and new moon. These phases reflect changes in the amount of the lighted surface of the moon that we can see from Earth.

photosynthesis The process by which green plants use carbon dioxide from the air and water from the soil, in the presence of sunlight, to manufacture molecules

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of glucose. Glucose is a simple sugar that the cells of the plant then use to make energy for the plant to carry on its functions, including growth.

physical change Change in the physical properties of a substance, that is, in the properties we can readily observe with our senses.

physical science The branch of elementary school science that includes the exploration of nonliving materials, their interactions, and interactions between matter and energy.

planets Principal members of the solar system that move around the sun. In order of their distance from the sun, the planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Planets shine by reflecting the light of the sun or other stars.

planning an investigation Determining a reasonable procedure that could be followed to test an idea. This includes listing the materials needed, writing out the procedure to be followed, and identifying which experimental properties will be kept the same and which will be changed.

Plantae (plants) The kingdom of all land plants, that is, multicelled organisms that make all their own food through photosynthesis.

potential energy The energy an object has because of its position; stored-up energy. When potential energy is set free, it is changed into kinetic energy.

predicting Estimating the outcome of an event on the basis of observations and, usually, prior knowledge of similar events.

prior knowledge What an individual has learned from all his or her previous experiences. This plays a crucial role in determining how the person integrates a new concept.

probe An electronic sensor, connected to a computer or other wireless handheld device, that allows the user to record real-time data about the environment.

professional development The process by which teachers strive to improve their practice in order to grow in their profession. It is generally based on inquiry into their own teaching practices, active engagement in their own research, and teacher workshops and courses.

Protista (protists) A kingdom of simple organisms, consisting mainly of algae, except for blue-green algae. Other protists are protozoans like the amoeba, paramecium, and euglena.

proton A positively charged particle in the nucleus of an atom.

R

recording data Writing down (in words, pictures, graphs, or numbers) the results of observations of an object or an event.

reflective teacher A teacher who thinks deeply about his or her teaching practices, the needs and identities of the students, and what the teaching is intended to accomplish.

respiration The metabolic process by which cells take in the oxygen they need and give back carbon dioxide as a waste product.

respiratory system The system that supplies the oxygen needed by body cells and carries off their carbon dioxide waste.

rubric A set of criteria used to determine the scoring value of an assessment task.

S

satellite A natural satellite is any heavenly body that travels around another heavenly body. The moon is a satellite of the Earth, and the Earth–moon system is a satellite of the sun.

scaffolding Providing temporary support or guidance to a learner who needs help to reach understanding of a concept or process. The scaffold can take such forms as key questions, important facts, a structure to frame the problem, and modeling or demonstration by the teacher.

science and engineering practices (SEPs) The use of a particular set of practices for engaging in scientific inquiry and engineering design providing insights into how scientific knowledge develops and gaining an understanding of the work of engineers.

science assessment A process of collecting information that is used to determine the quality and character of an individual or group performance in a science learning experience.

science autobiography A personal description of one's lifelong experience with science, in or out of school.

science circus A science activity that consists of several stations at which the visitors are asked to perform certain tasks and record their results or reactions.

science conversation A direct discussion between a teacher and an individual student about a science learning experience. This activity allows teachers to ask students to elaborate on their ideas—a good way to determine the depth of a student's understanding. Through such conversations, teachers gain important

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clues about how students construct personal meaning, and these clues then influence future instruction. Also called *science interview*.

science journal A personal journal in which the writer focuses on nature and natural events in his or her daily experiences.

science notebook A notebook in which students record their observations, reflections, questions, predictions, and conclusions during a science investigation.

science pedagogical content knowledge (PCK) Refers to science content knowledge that is transformed by the teacher into a format that makes it understandable to students.

scientific law A statement about principles or patterns in nature, indicating relationships between or among facts. Laws have endured over time and have consistently been tested; but, like theories, they are not absolutely "proved."

scientific literacy The ability to use the processes of science to make important life decisions; in particular, the ability to explore a problem through careful reasoning.

scientific method The typical process that scientists use in the course of studying natural phenomena, including steps such as observation, forming a hypothesis, and experimentation to test the hypothesis.

scientific observations As contrasted with everyday observations, scientific observations are perceptions of the natural world or a phenomenon that are made as part of a specific disciplinary context and students are noticing specific characteristics and recording their observations.

scientific theory *See* Theory.

sedimentary rock Rock formed when sediments, eroded from rocks on the earth's surface, are deposited by rivers into coastal basins or large lakes. These sediments are compacted and become rock through a process called lithification.

seed leaf *See* Cotyledon.

seed plant *See* Angiosperm.

series circuit An electric circuit in which the current has only a single pathway through the entire circuit.

simulation A computer program, virtual construction, or other procedure that imitates a real-world experience.

solar system The sun and the group of heavenly bodies that move around it. The sun is the only member of our solar system that is a star.

solid A state of matter with a definite size and shape.

sound A form of energy that is produced by objects moving back and forth or vibrating.

spectrum The band of colors seen when visible light is separated into its component wavelengths, as in a rainbow. The *electromagnetic spectrum* also includes other forms of electromagnetic radiation that we cannot see, such as ultraviolet light, infrared light, radio waves, gamma rays, and cosmic rays.

spiraling of curriculum Engaging students in the same topic of study at different grade levels, so that the topic is explored at greater depth in later grades.

star A heavenly body that produces its own light. There are billions of stars in the universe, including our sun. About 3,000 stars are visible with the naked eye.

states of matter The basic forms in which matter is found: solid, liquid, and gas (and a state that is rare on earth, plasma).

station assessment An assessment activity in which workstations are set up around the room to create a genuine context for the students to perform tasks. The students typically use an answer sheet to respond to the questions at each station. Each workstation assesses a different aspect of the science unit.

summative assessment Assessment at the end of a unit or course, used to document students' achievement or to evaluate the end product of a student's learning activity.

suspension A mixture in which solid particles do not dissolve but literally are suspended in a liquid.

T

taxonomy An entire classification system, such as the scientific classification of all living things into categories ranging from kingdom to species.

teacher research *See* Action research.

testing Assessment of students' learning by means of teacher-made tests or state and local tests designed by educational agencies or testing services.

theory A comprehensive explanation of some aspect of nature that is supported by a considerable body of evidence—in other words, the best explanation we currently have for why something is so.

tide *See* High tide and Low tide.

U

unit of study A segment of the curriculum that includes several lessons designed around a central theme or topic.

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Universal Design for Learning (UDL) The attempt to design all products and environments, including learning environments, to be as accessible as possible by all people, regardless of age, ability, or situation.

V

variable The property or condition of a scientific investigation that will change when experimental conditions are changed.

vegetable An edible plant part that is the root, stem, leaf, or flower of the plant.

vertebrate An animal with a backbone. There are five vertebrate groups: fish, amphibians, birds, reptiles, and mammals.

volume The amount of space an object takes up. Liquid volume is typically measured in milliliters and liters; solid volume, in cubic centimeters and cubic meters. When we refer to the *size* of an object, we usually mean its volume.

W

wait time The time that elapses between the moment a teacher asks a question and the moment the teacher selects a student to respond, offers a clue, rephrases the question, or otherwise moves ahead with the lesson.

weather The short-term conditions of the atmosphere in a particular place (compare to *climate*).

weathering The wearing away of rocks on the earth by the action of the sun, air, and water.

work The act of applying a force to move an object through a distance.

Y

year The time needed for a planet to make one complete turn or revolution about the sun.

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