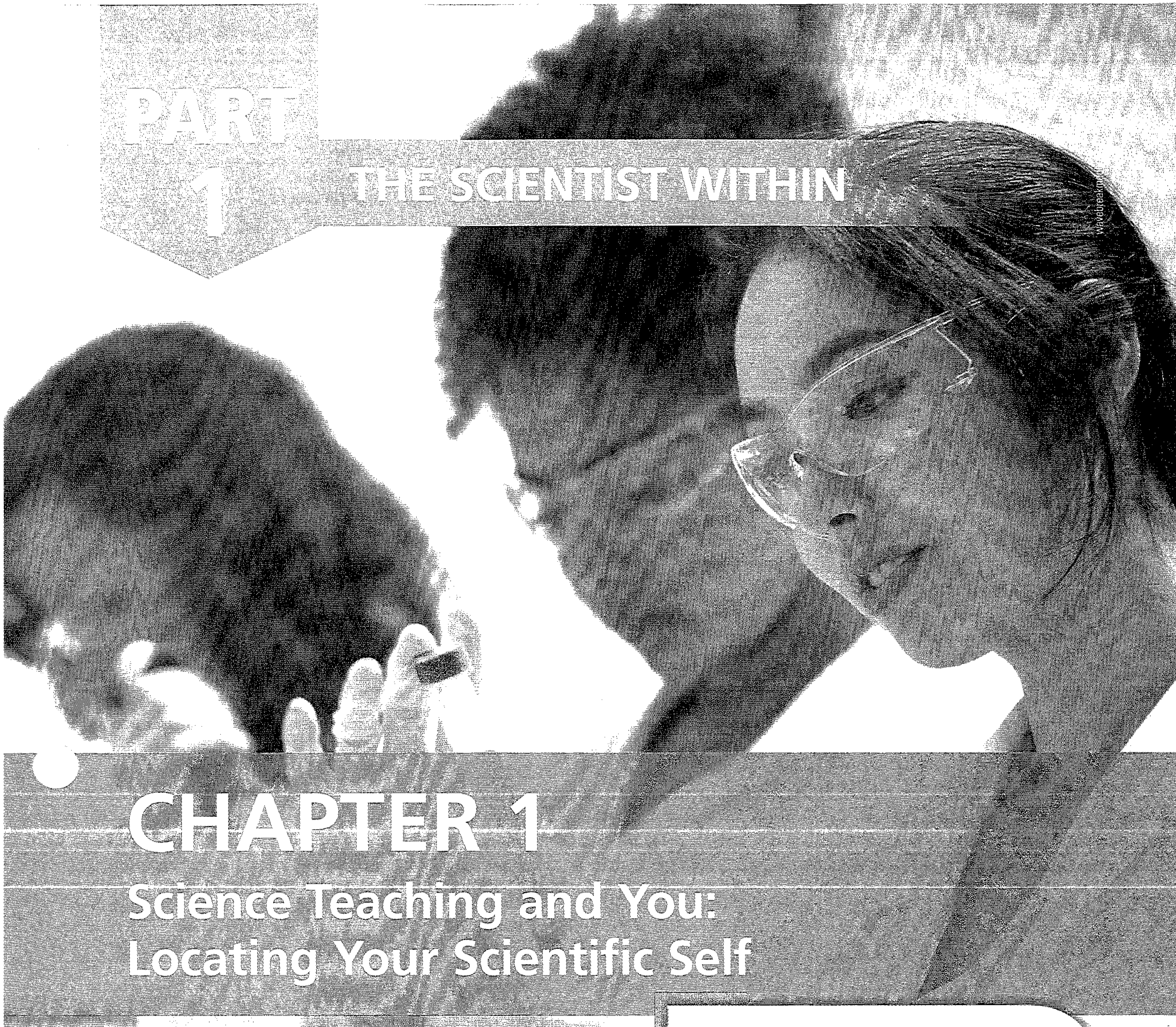


PART 1 THE SCIENTIST WITHIN

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

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.

1-1a The Scientist Within

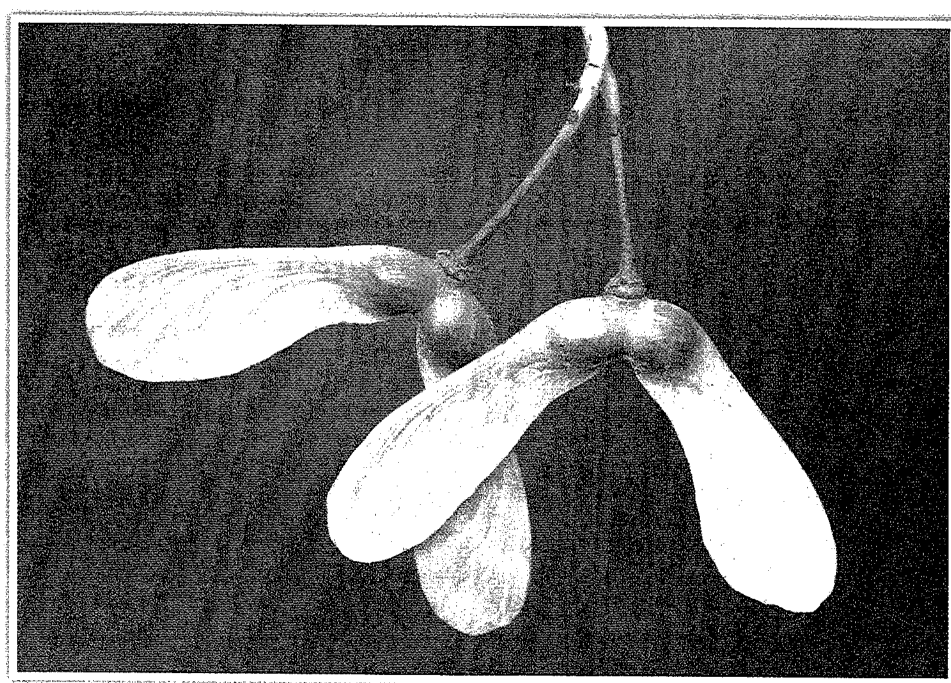
Where I grew up, in an inner-city neighborhood of New York, summertime recreation was usually afforded by the local park. In addition to playgrounds and sprinklers, there were grassy fields and trees. I often occupied myself by lying in the grass and watching the insects on their journey through the 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



AlessandroZocc/Shutterstock.com

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

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 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.

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).

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.

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.

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

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 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.

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 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.

1-2d 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.

1-3a Key Tenets of Constructivist Theory

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.

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.

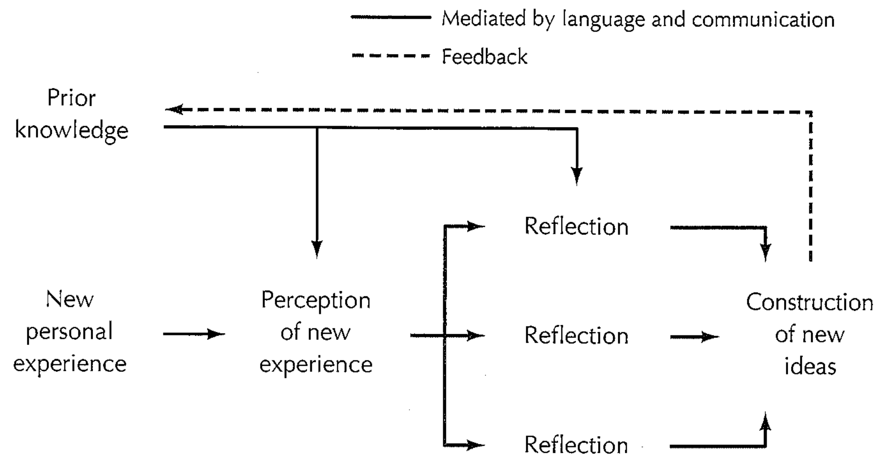


FIGURE 1.2 Constructing meaning from experience: a generalized diagram of a typical process

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.

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.

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.

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 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.

1-3b 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

"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

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.

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.

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?

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

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:

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.

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.

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?

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.

1-4b 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 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 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.

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.

1-5a 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.

1-5b 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 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.

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.

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.

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

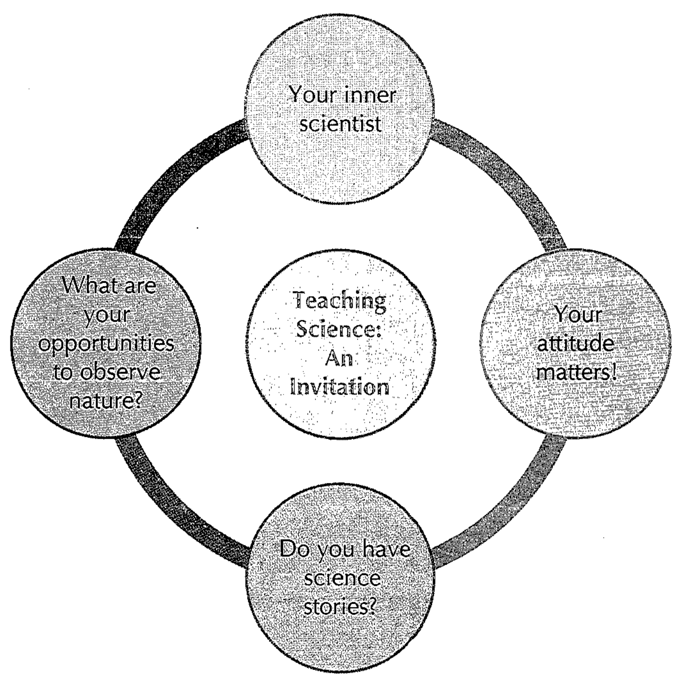


FIGURE 1.3 Teaching science: an invitation

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!

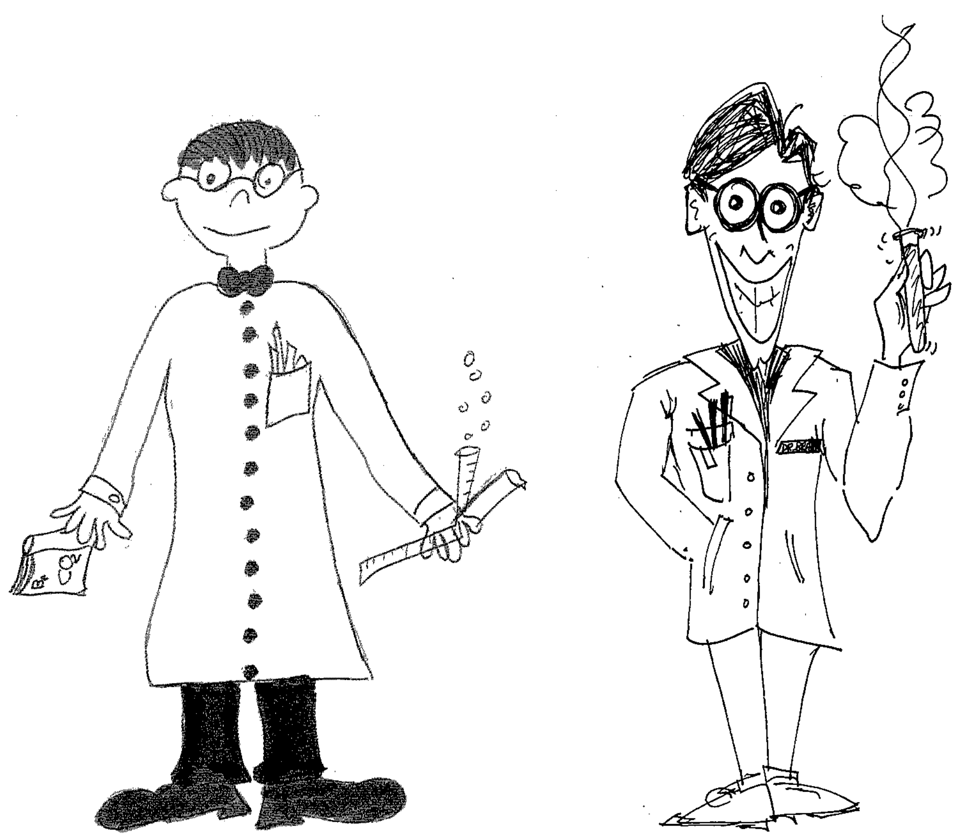
feelings about science. As you engage in these activities, you will learn more about your scientific self. If you were "turned off" to science in secondary school and college, this chapter should help you become more comfortable with it. The important thing is to acknowledge your feelings and consider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



Janice Koch

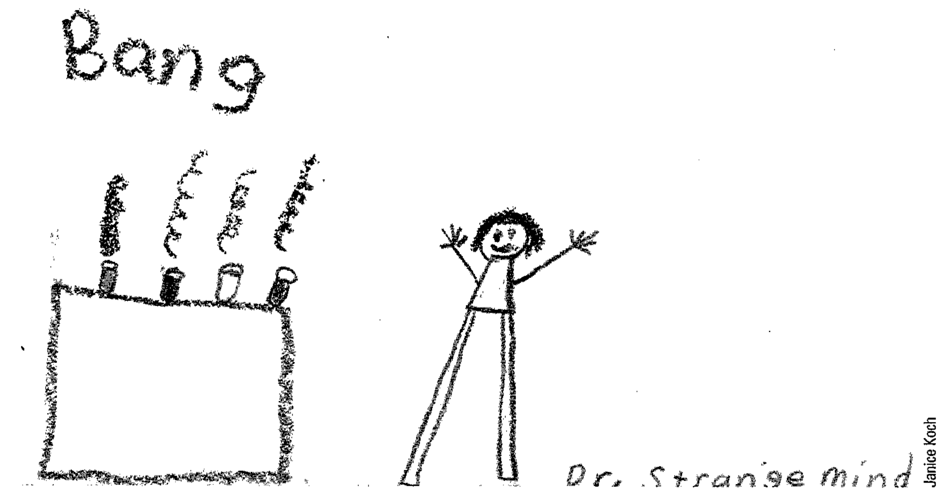
FIGURE 1.4 Responses by two preservice teachers to the assignment "Draw a scientist"

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

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.

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.

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. . . .

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?

1-11a 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.

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."

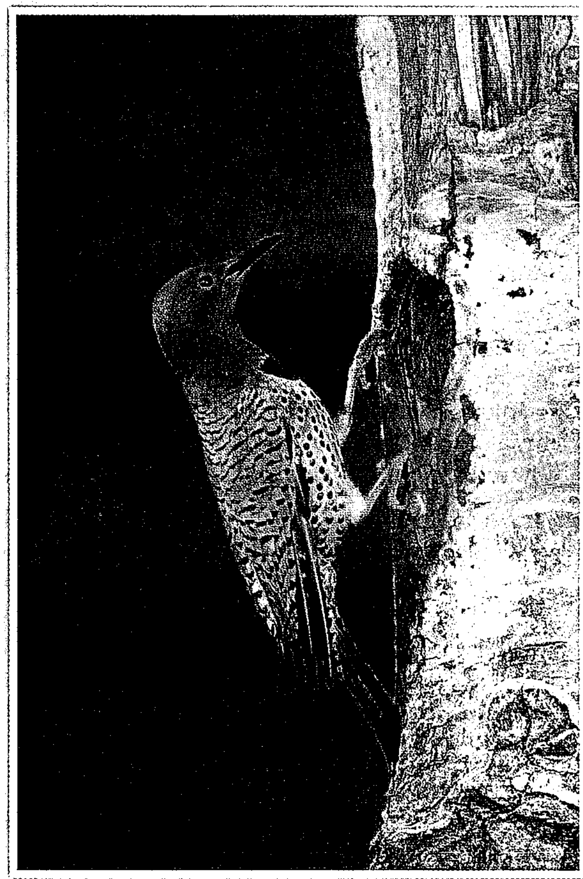
Quietly I stared at them, and then, fearing that the mother bird would return at any moment, I walked away. Now I am wondering what type of bird this is. It's not one that I recognize.

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.



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 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.

1-11c 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.

1-11d 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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