Chapter 1

I Know What Science Is!

It's an Experiment!

Learning Objectives

After reading Chapter 1, students will be able to

- Recognize and describe the basic tenets of science and scientific knowledge
- Identify the National Science Education Standards (NSES) associated with inquiry and the nature of science
- Describe science as a body of knowledge, processes, and a way of knowing

NSES TEACHING STANDARDS ADDRESSED IN CHAPTER 1

Standard B: Teachers of science guide and facilitate learning.
In doing this, teachers

- focus and support inquiries while interacting with students;
- orchestrate discourse among students about scientific ideas; and
- encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

Standard D: Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science. In doing this, teachers

- structure the time available so that students are able to engage in extended investigation;
- create a setting for student work that is flexible and supportive of science inquiry;
- make the available science tools, materials, media, and technological resources accessible to students; and
- identify and use resources outside of school.

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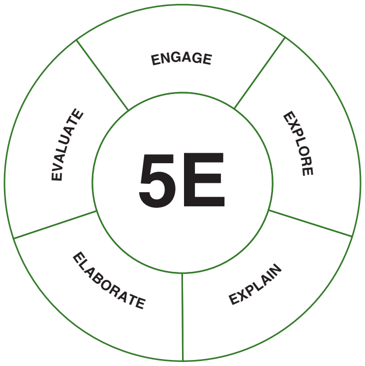
Introduction

This book is for you, the K–8 science teacher. It is important that you understand the approach you will find here is different from other science methods textbooks. First, you will find that each chapter is organized around an inquiry approach supported by the National Science Education Standards (National Research Council [NRC], 1996) and advocated as an effective way to teach K–8 science through inquiry—an approach discussed in more detail in Chapter 8. The organizing framework for each chapter is an inquiry approach known as the 5E instructional **model**. The five "E's" of this approach refer to a sequence of phases: **E**ngage, **E**xplore, **E**xplain, **E**laborate, and **E**valuate. In brief, the **engage** phase motivates students and seeks to uncover students' prior ideas of the concept to be taught. The **explore** phase is associated with student activities, and the **explain** phase follows with teachers' questioning students by drawing on the science activities conducted in the classroom. The **elaborate** phase requires a new application of the concepts learned, and the **evaluate** phase is an evaluation of student learning. Because the 5E model is highly student centered, each chapter embeds activities within each of the phases that are designed for you to examine or perform. In essence, the chapters are designed to be interactive, while bringing to life the 5E model for teaching K–8 science. Our vision, therefore, begins with you, and our goal for you is to broaden your understandings of science, scientists, and science teaching using the 5E model. As such, we will introduce ideas, concepts, and processes that you need to know and understand before we ask you to apply and use them with your students in your science classroom.

So, let the journey begin.

When you think of science, what do you think about? Do you think of your science experiences in school? Do you think of the science books, vocabulary, and concepts that you had to learn in school? Do you think of a science project you did in elementary, middle, or high school? Do you think about science experiences outside of school? We know that we ask a lot of questions, but your understanding of science as a field of study with its own characteristics is important. What you think and know about science will be reflected in what and how you teach shaping the K–8 science teacher you will become. In this chapter, we will explore those traits that define science and scientific knowledge as a discipline that is somewhat different from other disciplines. You also will examine how science and scientific knowledge are viewed in light of the NSES (NRC, 1996) for envisioning effective science teaching and learning.



Let's start with you. Before you read further, take a few minutes to take a paper and pencil and draw a scientist or what you think a scientist might look like.

After you complete your drawing, share it with one of your classmates or ask a friend to draw a scientist and take a look at each other's drawing. Reflect on what details you and your peers have included or omitted. Write statements about what the drawing or drawings tell you about the individuals' images of a scientist (i.e., mad scientist). After having explored your image of a scientist, reflect further. What is the work of scientists really like? What would you say if one of your students asked, "What is science?" or "How is science done?"

Now that you have completed this activity, examine your drawing using the "Draw-a-Scientist Test" (DAST) checklist (Table 1.1) to gain insights into views of scientists and the stereotypical characteristics that individuals commonly imagine (Finson, 2002, 2003; Finson, Beaver, & Cramond, 1995). Keep these ideas in mind as you draw on your inner scientist in the following activity.

Table 1.1 Draw-a-Scientist Test (DAST) Checklist

Stereotype characteristics	In the drawing	Not in the drawing	Examples
Lab coat			
Eyeglasses or goggles			
Facial hair			
Symbols of Research • Science instruments • Lab equipment • Microscope, flasks, beakers, test tubes, animals, or others			
Symbols of Technology • Types: Computers, calculators. cell phones, television, etc. • Products: Rockets, etc.			
Symbols of Knowledge • Books, cabinets, clip board, pens in pockets			
Captions or Thought Bubbles • Formula, equations, classification, period charts, etc.			
Male			
Signs/posters/labels			
Unkempt appearance			
Caucasian only			
Middle-aged or elderly scientists			
Signs of secrecy or warning signs: (Private, Do not enter, etc.)			
Indications of danger			
Other images			
Evil or sinister (stereotypes), e.g., mad scientist			
Eccentric appearance (geek)			
Neutral			

Stereotype characteristics	In the drawing	Not in the drawing	Examples
Positive (smile, positive captions)			
Female			
Scientist working inside			

Note: Modified from Finson, K. D., Beaver, J. B., & Cramond, B. L. (1995), Development and field test of a checklist for the Draw-a-Scientist Test, *School Science and Mathematics*, *95*, 195–205.

Engage

Making Observations and Inferences With a Fossil

Now, think for a moment about a core skill needed to conduct scientific investigations. Did the word "observation" come to mind? It's a word you've heard many times before, but how would you define it? An **observation** is any information gathered through your senses or with instruments to extend your senses. Eighty-five percent of the observations made by sighted people come from one sensory organ, our eyes. However, when teaching students about the process of observation, it is important to stress that the best observations use more than one sensory organ to collect data. Be aware that when students make observations they also make explanations, generalizations, or draw conclusions based on their observations and experiences. These general statements are called **inferences**, and they may or may not be correct. Inferences are explanations, generalizations, or conclusions a person makes based on observations and experiences. As a science teacher, it is important to recognize the difference between the skills of observation and inference when teaching students. Consider the following sentence: "I ran into the kitchen and saw Mel standing by the table holding a cloth dripping water." To get you started, here is one observation: *There was a table*. Another observation is *Mel was standing*. An inference is an explanation that may or may not be correct. An inference you might make is that *Mel is a male*. Mel may or may not be a male. We do not know. Another inference is that *Mel spilled water and was cleaning it up*. So, look at the sentence again. What other observations and inferences can you make?

Making observations and inferences are fundamental skills in science; let's put those skills to work. Imagine you were fortunate enough that your paleontology professor, who needed a few extra assistants, offered you an opportunity to go on a dig to Morocco over the summer. During that trip, you found a most unusual fossil. You photographed the fossil and, with the help of your peers, you seek to find out what you've found. Now, look at the fossil you found (see Figure 1.1).

Teacher's Desk Tip: Addressing Diversity in Your Classroom

Consider adaptations for students with diverse needs. How would you adapt the fossil activity for a child who is visually impaired? Perhaps you could make clay model of the bones, or use actual fossils. Can you think of other adaptations?

Figure 1.1 Fossil bone

Make a concept web (graphic organizer that can be used to organize ideas, thoughts, concepts, and skills around a central topic or theme) or a list of statements about what you know about fossils. In making the web, consider the following questions: What are fossils? How do they form? Where do we find them? What process(es) create fossils? How do you think scientists reconstruct organisms from fossils? What tools do scientists use to reconstruct organisms from fossils? Next, look at the fossil pictured in Figure 1.1 and create a list of observations about it. What inferences can you make about the fossil? Describe the relationship between your observations and your inferences. Explain.

Explore

Digging Into the Nature of Science

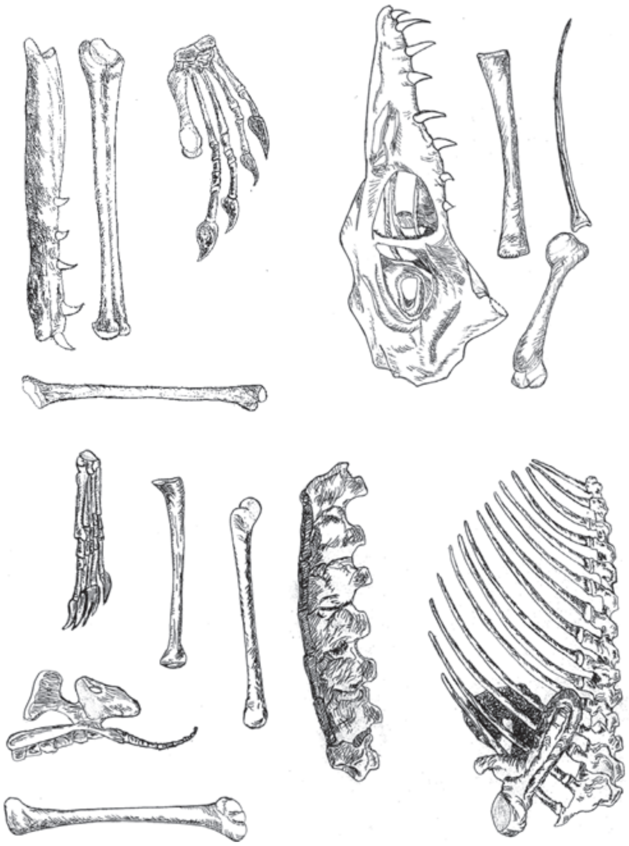
Your exciting discovery has led you to pursue a dual degree in education and paleontology. You spend your summers at various archaeological digs, but that fossil you found remains on your mind. You're driven to know more. An opportunity to join a funded expedition back to Morocco and additional sites where similar fossils have been found becomes available through the National Observation System grant program. Fortunately, the university's scientific team was awarded a large grant and can assemble research teams to gather more information about your fossil find. You remember how excited your science methods peers were when you shared your pictures of the fossil. This time, you help arrange the research teams and invite some of your science methods peers to become a part of the teams.

The plan is to send out teams to the following places: Morocco, Siberia, the Badlands of South Dakota, Nigeria, and the Australian Outback. Based on past findings, each team is given GPS (global positioning satellite) coordinates for the location of its specific dig. Because of the remote locations and the political climates in some of the selected locations, digs must occur only at the approved sites. (We don't want to create any international incidents!)

As the summer ends and the school year is about to begin, the teams find they're not able to fully excavate the fossils and are forced to rely on pictures and sketches. Each team has a few more weeks on location before returning home, so, based on the sketches made (Figure 1.2), teams construct models using the "highly technical" tools of paper, pencils, and scissors (sorry, you didn't get *that* much funding) and begin working on models of the skeletal reconstruction. You, as a member of the team, will build a model and make a drawing of what you think the organism may have looked like. Answer the following questions to guide your investigation. Be prepared to discuss the evidences you have to support your reconstruction. The National Observation System program directors, Professors Eed Notsdlog and Arual Yenwod and hopefully your instructor, will arrange for a conference where the teams will meet to share their findings.

When you think of science, is this the kind of activity that comes to mind? What if we told you the activity is more than an exercise that simulates work done by paleontologists? In fact, it is intended to illustrate the nature of scientific knowledge and how it is produced. It is also an illustration of the way scientists may conduct research, depending on their field of study. So what does this activity reveal about scientific knowledge? How does this activity relate to the **nature of science** and scientists? Now, think about the scientist you drew. If you were to

Figure 1.2 Fossil Bone Set for Reconstructing a Mystery Organism



QUESTIONS

1. What are your observations?
2. What inferences did you make from the fossil sketches provided?
3. How would you describe your model (or drawing)? What are models? What role do you think models play in science?
4. What strategies or ideas did you use as you reconstructed the organism?
5. How confident are you about your reconstruction?
6. What do you think the organism looked like? Sketch it.

now draw the paleontologists for the fossil activity, would they look like the scientist you drew earlier? The DAST checklist (Table 1.1) reveals many stereotypical characteristics of scientists that are held by many individuals. The point is that many of the characteristics may not be representative of what a scientist looks like or the research he or she does. The activity should challenge you to rethink your views of science and scientists. As you read the next section, consider the focus questions to direct your thinking on the nature of scientific knowledge, the ways science is carried out, and how science is viewed in our society.

> *Science is the belief in the ignorance of the experts.*
>
> Richard Feynman
>
> How does this quote challenge your ideas about science? What type of disposition or attitude is Feynman advocating in the quote? Who is Richard Feynman?

Explain

Focus Questions

1. What is science?
2. What are the basic principles of the nature of science? How are these principles different from your experiences with science?
3. Describe **scientific theories and laws**. How are scientific theories and laws developed?
4. What is scientific inquiry?
5. How is scientific inquiry conceptualized by the NSES (NRC, 1996)?

The Nature of Science and Scientific Knowledge

As a K–8 science teacher, it is important that you recognize the nature of science, scientific knowledge, and the work of scientists to make the science taught in your classroom more relevant. This means examining aspects of science you may not have considered before. Imagine sitting on a high boulder surrounded by lush evergreen trees, listening to crystal-clear water rushing by or watching an eagle soar over the river below and swoop down for a trout. Do you hear and recognize a woodpecker tap-tap-tapping among the trees? Your sensory experiences are only the beginning of what is really happening around you. Why is the water moving so fast? What is the woodpecker really doing? How does it find food? How does the trout survive in fast-moving water? Why do the evergreens grow so tall? If we think about it as scientists, we might consider that everything in this scenario is centered on the energy of the sun. The trees compete for light to produce food through photosynthesis. The algae and plants found in the water and along the shore use sunlight to grow, and then become food for small fish and insects that in turn become food for the trout, and the trout for the eagle. When we stop and view the natural world or the universe, it generates questions that make us wonder and seek to explore its mysteries much as a child wonders how her favorite toy dinosaur roars or why stars appear to twinkle at night. The way in which *you* view the natural world shapes your views of science, scientists, and of how knowledge is generated through scientific activities.

So what is the nature of science? In general, it is a way of knowing guided by commonly held principles that result in scientific knowledge. Though some may disagree on the exact details or principles underpinning the nature of science, there are some principles or tenets on which most individuals would agree. These are described in the list below (Lederman, 1998).

1. *Scientific knowledge is developmental and subject to change* (National Science Teachers Association [NSTA], 2000). Scientific knowledge is not absolute.

Do you remember learning the names of all nine planets in our solar system? Did you use a mnemonic device like, "**M**y **V**ery **E**legant **M**other **J**ust **S**at **U**pon **N**ine **P**orcupines," to remember their order (the first letter of each word is the first letter of the planets in their proper order)? Within the past ten years, scientists have debated whether Pluto would remain a planet or be demoted to a Kuiper Belt Object (minor planets). In 2006, the

International Astronomical Union, which is charged with the classification of astronomical objects, reclassified Pluto to a dwarf planet. Older science textbooks, museum displays, and planet mobiles that include Pluto will need to be changed! So remember, scientific knowledge is not absolute; in fact, it is a work in progress that can be changed or even replaced. Guess it's time for a new mnemonic: "**M**y **V**ery **E**legant **M**other **J**ust **S**at **U**pon **N**eedles!" Consider the fossil reconstruction in the engage phase above. Do you think your model is absolute? Probably not: As new information in science arises, scientific knowledge is subject to change.

2. *Scientific knowledge must be at least partially supported by empirical data.*

Harold Varmus, Nobel Prize winner, with the National Institute of Health, stated at a 1996 Harvard University commencement address, "Science is a way of thinking—making judgments, often creative ones, that are based on evidence, not on desires, received beliefs or hearsay" (Varmus, 1996, p. 119). These "evidences" are empirical data from experiments or observations drawn from the senses or technological tools that extend the senses. Think about the fossil activity: What was your empirical data? Did you take measurements of the bone sockets? Did you compare shapes and sizes of the bones? Did you make careful, systematic observations of the joints? If you did, then you were gathering empirical data or "evidence" to support your reconstruction.

3. *Scientific knowledge, in part, comes from the creativity and imagination of the scientists* (NSTA, 2000). Scientific knowledge combines empirical evidence and creativity.

Did you use creativity and imagination in the fossil activity? Maybe you were creative and found that you had "extra bones" that were not part of the original organism. Instead, the bones were from something the organism ate. We have seen creative students take the paper bones and hold them up to the light to see if they could align the joints to match in shape and size. Scientists, too, use creativity in the way they ask questions, the methods they use, and even in the way they present the findings of their work.

4. *Scientific knowledge is inherently subjective to some degree and therefore not objective, as is often assumed.*

In the fossil activity, think of something you objectively know or observed about the bones (that is, something that is impartial, neutral, without bias)? You might take a measurement of the width, curve, or length of the bones and joints. Now, think of something you know about bones from a subjective stance (intuitive or instinctive). You may look at one bone and think, intuitively, that it looks like part of a jaw or a face or a tail or a hand. Both of these ways of knowing is important in understanding the nature of science. It's a myth to think that all science is objective.

5. *Scientific knowledge involves both observation and inference.*

Scientific knowledge comes about through observations made with the senses or with technology that extends the senses. Furthermore, it involves inferences that are statements based on observations that lead one to generalizations or conclusions. Did you make inferences based on observations of the teeth in the skull bone fossils you examined earlier? Did you infer the kinds of food the organism may have eaten? Did you make other inferences?

6. *Scientific knowledge is amoral—neither good nor bad.*

In a commencement address at Morgan State University in 1997, President Bill Clinton acknowledged this tenet by stating that science has no soul of its own. Clinton noted that, historically, scientific knowledge often emerges faster than our ability to understand its application. For instance, in April 2003, the entire gene sequence (genome) of the human species, *Homo sapiens*, was mapped. For the first time, scientists could decode and read the blueprints that make up human life. Now, what we do with this scientific knowledge is another matter. For instance, with this knowledge scientists have the opportunity to learn more about the genetic factors that cause diseases and to apply that knowledge to the prevention, diagnosis, and treatment of the diseases. Sounds very promising, doesn't it? On the other hand, what if insurance companies use this knowledge for genetic prescreening and only insure those individuals who do not show any propensity for a serious disease? Scientific knowledge, itself, is neither good nor bad. However, because the applications of scientific knowledge affect us, we must be scientifically literate.

7. *Science is influenced by social factors; it is a social endeavor* (McComas, Clough, & Almazroa, 1998).

It only takes looking back at the history of science to recognize that the directions that science progresses are often influenced by social needs and conditions. Recall what happened in the United States after the Soviet Union launched Sputnik I into space in October 1957. Research related to space and rocketry intensified so the United States could regain a competitive edge in the space race. Today, we see social influences on science as we look at the national emphasis on finding and developing economically feasible renewable or alternative energy sources. As a result of this social factor, it is likely we will see more funding shift toward research associated with these areas, which generally means a growth of scientific knowledge in these fields.

8. *There is no single set or sequence of steps in a scientific study* (NSTA, 2000). Scientists use a variety of methods to approach their questions and problems.

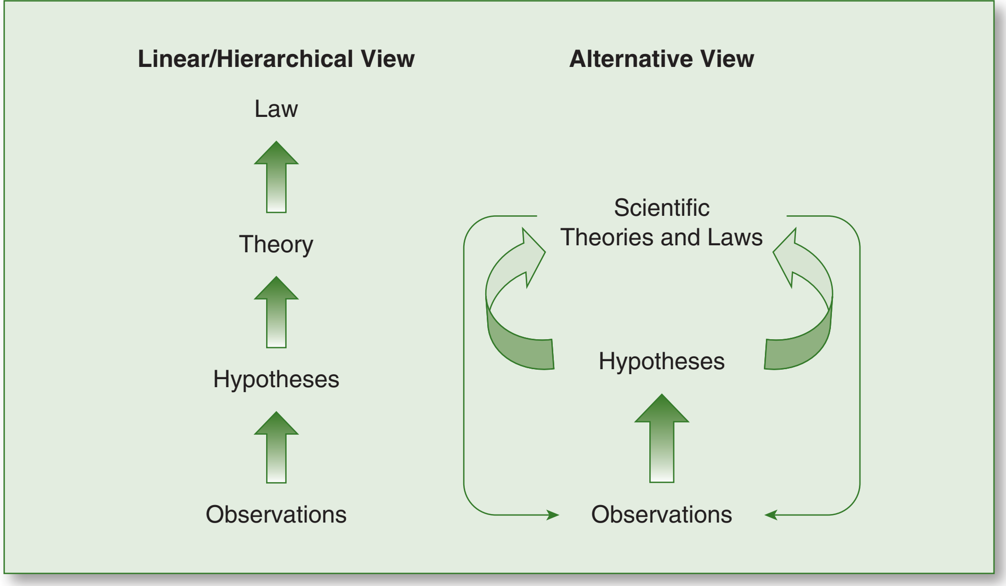
Think back to the fossil activity. Did you reconstruct the fossils in the same manner as others performing the task? Did you follow the scientific method you learned in school during the reconstruction? Our experience with this activity has repeatedly shown that students use many different approaches. Some individuals reconstruct the skeleton using trial and error. Others use more systematic approaches based on skeletal structures that they have studied previously, and still others are creative and put the bones in the most unusual positions. In short, not everyone uses the same approach in reconstructing the fossil bones. These different approaches to solving problems support the notion that there is no single scientific method. Throughout the history of science, there have been many debates regarding a single scientific method. Thomas Kuhn, in his influential book *The Structure of Scientific Revolutions* (1962), clearly suggests that scientists have worked within many paradigms or frameworks. Depending on the field of science and the researcher, the way scientific research methods are conducted will vary.

To understand how to teach science to children, it is important that you be aware of your understandings and perhaps a few misunderstandings surrounding the Nature of Science. For instance, recall the tenet that there is no single scientific method. Did you have to memorize the scientific method while you were in school? We suspect you did. Well, we did as well. Unfortunately, the notion that there is a single scientific method exists. It perpetuates a notion of a linear and hierarchical progression of the development of scientific knowledge from observation to law, which is not necessarily the case.

Viewing science and the development of scientific knowledge through the dynamic interactions between hypotheses, theories, and laws is more realistic than the traditional, linear or hierarchical view for a couple of reasons (see Figure 1.3). First, theories and laws are different kinds of scientific knowledge (McComas, 1996). For instance, a theory is an inferred "explanation of observable events," whereas "laws are statements about the relationships among the observable events" (Abd-El-Khalick, Bell, & Lederman, 1998; N. Lederman, 1994; Lederman & Lederman, 2010). Second, laws and theories cannot be absolutely proven. Simply stated, we cannot guarantee that some happening in the future would occur in the same manner as prescribed by the scientific law. Theories and laws can change. Consider the picture you drew of the organism from the fossil reconstruction: Can you prove that your model is the exact reconstruction of the live organism? Not likely, so when teaching K–8 science, it is important to acknowledge that multiple approaches for investigating scientific phenomena are important. In addition, K–8 science teachers should assist students in understanding that scientific theories and laws represent different kinds of knowledge that may change if the theories or laws do not explain the current findings.

Consider Figure 1.3 and the narrative in *Your Science Classroom: Team Meetings and Planning*. How does Table 1.2 provide evidence that theories do not necessarily become laws? What does this suggest about there being a single scientific method? As a teacher, how would you describe a theory and a law to your students? How do scientific theories

Figure 1.3 Rethinking the Scientific Method (Hierarchical and Alternative Views)



Note: Adapted with permission. Lederman, N. & Lederman, J. (2010), *Avoiding De-Natured Science: Activities that Promote Understandings of the Nature of Science*. Available at http://msed.iit.edu/projectican/.

support the nature of science principle that science is developmental or tentative? What example could you provide to your students?

As you examine the examples of theories and laws in Table 1.2, you will find that some laws such as the Law of Gravitation has no theory associated with it, and that some laws were developed long before the theory that explain the phenomena. As you may have surmised, one can identify the nature of science tenets throughout the history of scientific discoveries. Now that you have read some of the principles that underpin the nature of science, inquiry, and scientific knowledge, let's turn our attention to descriptions of science.

YOUR SCIENCE CLASSROOM:
Team Meetings and Planning

Teaching Standard B: 3

How does this scenario reflect this standard?

Ms. Sung Lee, the seventh-grade science instructor at Ridge Quarry Middle School, has been working on her master's degree in science education at the local university. In her "Science Trends and Issues" class, her instructor shared Table 1.1, then engaged the class in a discussion of theory, law, and the Nature of Science. Ms. Lee was struck by her misunderstandings about the nature of science and wondered if her colleagues held the same ideas. At the weekly science team-planning meeting, Ms. Lee made copies of her class chart (see Figure 1.3) for her colleagues and asked, "How do you teach students about the scientific method? How do you handle teaching about theories and laws in your classrooms?"

Tom Alvarez, the eighth-grade science teacher replied, "I have them learn the scientific method as presented in the textbooks. The text doesn't cover a lot on this, but, from what I remember, it basically says theories are tested ideas that hold up over long periods of time. Given more time they become laws." Sung said, "Yeah, that's what I thought, too. I was using the same idea, but take a look at this chart my professor gave the class as we were discussing the nature of science. It surprised me that theories and laws refer to different kinds of knowledge and that theories don't necessarily become laws!" Tom had a puzzled look on his face and asked Sung to explain. "Well, if you think about the nature of science, theories, and laws through history we find that science is not absolute, but is self-correcting. Think about it: If it were absolute, a theory would never change, right? And a law would never change either. But they do. Consider Ptolemy's geocentric theory of the solar system that the earth is the center of the solar system. As science advances and new observations are made, we came to understand that Ptolemy's theory no longer held up under new evidences. So Copernicus' heliocentric theory that places the sun in the center of the solar system became the most comprehensive theory for the time period."

Tom replied, "Well, I understand what you're saying about that, but I am not sure how you're relating this to the scientific method." Sung said, "Well, there are different kinds of sciences that use different methods to address their questions and so a single method makes no more sense than having all theories turn into laws. Now, if you look at Table 1.2, pay attention to the dates and the relationship between them and it'll give you a few clues. Look closely at the dates—what does this tell you about the relationship between theories and laws? It's not as clear cut as we tend to teach it. These ideas not only make me rethink how I am teaching science in my classroom, but also makes me rethink how to teach students about the different ways that scientific knowledge is generated." With a grin on his face, Tom asked, "Hmm, how does evolutionary theory fit into this?" to which everyone chuckled and quickly noticed that their planning time was over. The two additional team members, Lynn and Sue replied, "Guess we'll have to continue this conversation next time, Tom!"

Table 1.2 Comparison of Theories and Laws

Scientific Law	Scientific Theory
Boyles Law	**Kinetic Theory**
Robert Boyle, a physicist, stated that the pressure (*p*) of a given quantity of gas varies inversely to its volume (*v*) at constant temperature (1662). French physicist Edme Mariotte also discovered the relationship (1676).	Kinetic Theory proposes that the pressure of molecules is due to collisions between molecules moving about with a certain velocity. This theory underpins Boyle's Law, and is thought to have been first developed by Daniel Bernoulli (1738), though some suggest it was first developed by Rudolph Clausius and James Maxwell (1850s).
Law of Segregation and Law of Independent Assortment	**Chromosome Theory**
Mendel's Laws of Inheritance include the Law of Segregation and the Law of Independent Assortment (1865–1866). The Law of Segregation states that each pair of alleles separate when gametes are formed. A gamete will receive one allele of the pair. The Law of Independent Assortment states that two or more pairs of alleles segregate independently of one another during gamete formation.	The Chromosome Theory by Thomas Morgan and colleagues stated that chromosomes carry genes for each trait and chromosomes carry hereditary information (1915).
Law of Universal Gravitation	
Newton's Law of Universal Gravitation states that every mass in the universe attracts every other mass (1687). In his *Principia, The Mathematical Principles of Natural Philosophy,* he wrote that every particle in the universe exerts a force on every other particle along the line joining their centers. The magnitude of the force is directly proportional to the product of the masses of the two particles, and inversely proportional to the square of the distances between them.	None

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What Is Science?

Up to this point in the chapter, we've been talking about the nature of science and the processes by which scientific knowledge has been and is currently being developed. Now that you have a good idea of how scientific knowledge emerges, how can we apply that understanding to a definition of science? In other words, what do we mean when we refer to science?

If we asked any one of you for your definition of science, it is likely that we would get a variety of responses. For instance, most individuals think of school and view science as a body of knowledge related to the natural world. Some would define science as a way of viewing the world searching for explanations with the intent of understanding how the world works. Still others view science as a way of solving problems and using the solutions to explain how events, processes, and objects operate as they do. All of these definitions include dimensions of science.

Looking across the dimensions we find that science includes (a) a body of knowledge, (b) processes for conducting inquiry, and (c) ways of thinking reflected in the tenets that underpin the nature of scientific knowledge.

BULLETIN BOARD

Did you know the term "science" comes from the Latin word "scientia," or "knowledge"?

During the span of our careers, we have heard many definitions of science; one we find useful is simple and elegant. It came from a fellow science education professor, Dr. Steve Oliver, who was asked to describe his view of science. He replied, "Science is any activity that allows one to be intellectually independent with respect to the natural world." We find students' abilities to judge the evidences of an inquiry or read the findings of a study to determine the value of the evidences on their own captures the essence of science and **scientific literacy** that we must encourage when teaching K–8 students.

Connecting the Nature of Science, Classroom Inquiry, and the National Science Education Standards

At this point, you may be wondering why you need to know about the nature of science. Simply put, the answer is that your views of science and the nature of scientific knowledge will influence how your students come to view science. So, when you teach science, remember that scientists build concepts as they engage with and explore the world around them. The same should hold for students learning science. It is generally accepted by most educators that students, especially young students, learn through experience (Butts & Hofman, 1993; Dewey, 1998; Piaget, 1952, 1964). Teachers should plan explorations where students experience science and acquire knowledge as a process. This process draws on their observations and other information to form concepts about the phenomena under study. Over time, students should come to know that scientific knowledge is a work in progress that changes with new information. Therefore, scientific knowledge is always subject to change. However, it is important for students to know that, despite the possibility that the knowledge may change, it still represents the best explanations scientists have at the time.

Upon examining the nature of science and scientific knowledge, you may be wondering what science content is taught in K–8 classrooms. The state and national standards serve as your guide for answering this question. The NSES (NRC, 1996), which include both content and inquiry standards, is the go-to resource for all science teachers. The content standards are designed to provide a guide for teaching relevant science topics based on what students should know by the end of the fourth, eighth, and twelfth grades. Content standards include the core disciplines of life science, earth and space science, and physical science, with additional standards on science as inquiry, science in personal and social perspectives, and science and technology. The NSES are discussed in depth in Chapter 2, however, because science content goes hand in hand with inquiry let's take a moment to look at inquiry in the science classroom.

We all know that children are naturally curious about what they observe in their world. At times, they can ask what appears to be an endless string of questions in their search to find out how the world operates. Children, like scientists, seek explanations to the questions they pose. Students want to know how birds fly, why trees grow so tall, what causes rainbows, and why one ball dropped in the bathtub sinks another one floats, to name but a few.

Using students' questions and facilitating their search for explanations initiate students into the processes of inquiry (Duckworth, 1987; Johnston, 1996; Wray, 1999). So just how does one view inquiry? For some educators, like Cherif (1993), to inquire is to "seek knowledge and understanding by questioning, observing, investigating, analyzing and evaluating" (p. 26). In essence, his view suggests that scientific inquiry involves skills that allow the learner to experience the nature of science firsthand. Suchman (1966), an early leader in developing inquiry strategies and inquiry-based programs, suggested that inquiry strategies include presenting **discrepant events** where outcomes are unexpected or problematic situations where students observe, ask questions, test various hypotheses, and debrief through discussion. Teaching children science through inquiry involves providing opportunities and an environment for students to learn the skills necessary to conduct science explorations like a scientist (Layman, 1996; Wray, 1999). It also means that students learn key concepts and the language of science while experiencing inquiry opportunities.

Today, the NSES (NRC, 1996) serve as a guide for teaching science as inquiry. In particular, the standards provide guidelines to envision science as a body of knowledge, a process, and a way of thinking to gain understanding of the natural world. The standards for scientific **inquiry** stress that students have the

(1) abilities needed to conduct scientific investigations; and the

(2) understanding about science inquiry at all grade levels.

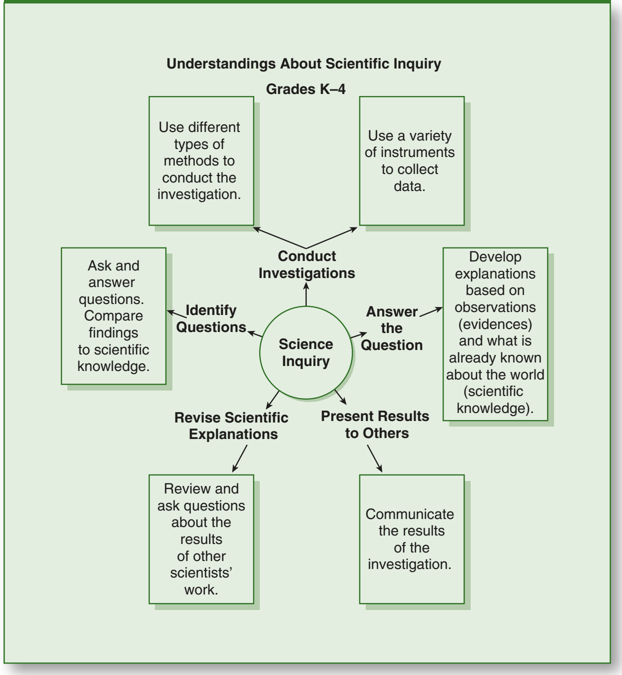
In other words, according to the NSES, K–8 students should *acquire skills* by asking questions, conducting experiments, using scientific tools to collect data, analyzing data, developing explanations, and communicating their findings. In addition, elementary and middle school students should also *understand about* science inquiry. This includes (a) answering questions in light of knowledge already acquired, (b) designing investigations based on the questions, (c) using instruments, technology,and mathematics in conducting investigations, (d) recognizing that strong explanations are based on evidence, (e) communicating scientific findings for critique and review by other scientists that lead to acceptance or replacement of the ideas for better ones, and (f) acknowledging that advances in science through logical skepticism can result in new or different methods, technologies, questions, and investigations (see Figures 1.4 and 1.5). You might have noticed as you read through the list of the ideas in Figure 1.4 and 1.5 that they are

Children continually explore science through informal, everyday activities. Many children observe rainbows not only in the sky, but also in the spray of a garden hose.

Author's Note:

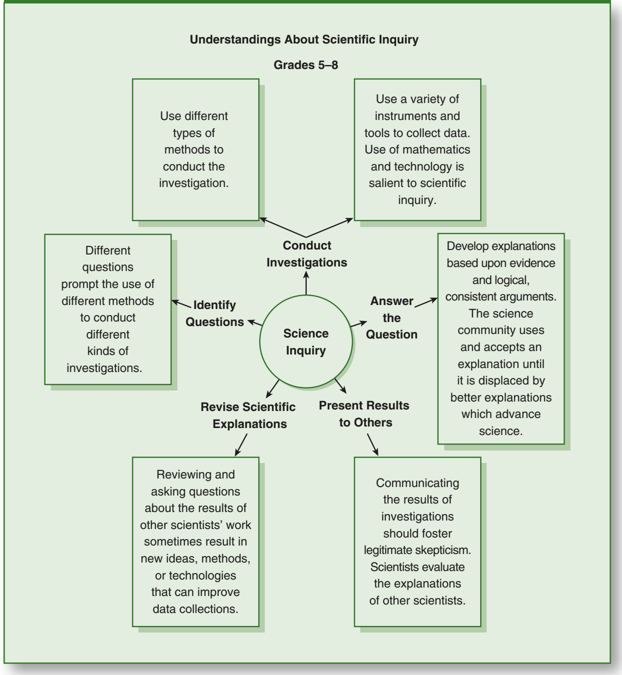
National Science Education Standards: You can download and examine NSES free at National Academies Press Library at www.nap.edu.

Figure 1.4 NSES on Inquiry for Grades K–4



Note: Adapted from National Research Council (1996), *National Science Education Standards*, Washington, DC: National Academies Press; and National Research Council (2000), *Inquiry and the National Science Education Standards,* Washington, DC: National Academy of Sciences.

Figure 1.5 NSES on Inquiry for Grades 5 –8



Note: Adapted from National Research Council (1996), *National Science Education Standards,* Washington, DC: National Academies Press; and National Research Council (2000), *Inquiry and the National Science Education Standards,* Washington, DC: National Academy of Sciences.

reminiscent of the discussion about the nature of science earlier in the chapter. If you did, you're right! K–8 science teachers should create learning environments that assist students in developing ways of thinking and acting that are associated with scientific inquiry and reflect the nature of science.

Technology and Science

The last section of this chapter focuses on the roles of technology in science, which often go hand in hand. The NSES (NRC, 1996) address science and technology in both the content standards and the teaching standards. Within the content standards, a distinction is made between science inquiry and technology. Scientific inquiry is motivated by a desire to understand the natural world, whereas technology and technological design are driven by the desire to meet human needs and solve our problems. According to the NSES (NRC, 1996, p. 106), students should

1. distinguish between natural objects and objects made by humans (K–4),
2. develop the abilities of technological design (K–8), and
3. develop understandings about science and technology (K–8).

Like science, technological advances and technology are human endeavors that attempt to solve problems. Technology often adapts the environment and science seeks new knowledge. In science, inquiry skills such as identifying the problem and developing ways to test hypotheses help solve problems. In technology, skills focus on the design processes. Through technological design there are often multiple solutions to a problem or need. Based on the design criteria, one or more solutions may be selected to accomplish the task. For instance, a colleague who teaches in a sixth-grade classroom had a student who had a head injury as a result of a bicycle accident. She used that teachable moment to integrate technological design in her classroom. Students examined a variety of bike helmets to evaluate and redesign them to make them safer. In doing so, students used their understanding of the physics of motion, physical properties of materials, and human anatomy to address a real-life problem. This is an authentic example of the partnership between science and technology. From ancient times through today, scientific work has incorporated technologies that generate new scientific achievements, often evoking a need for new applications of technology.

It is because science and technology are so interrelated and interdependent that technology plays an important role in the K–8 science classroom. Concern for the interconnections between science and technology has been a major theme identified in recent educational reform documents. Reform documents, such as *The American Competitiveness Initiative*, address the connections in a variety of ways that range from students' achieving literacy in science and technology for daily life, to functioning competitively in global information-based work forces of science and technology (Domestic Policy Council, 2006).

Now here's where we're really going to try to confuse you. So far, we've been talking about technology as it relates to science (content understanding and skills) in the K–8 science classroom, but we also think it is important that you, as a teacher, understand the important role that technology can play in teaching and learning science, which is often referred to as educational technology.

BULLETIN BOARD

Guidelines for Using Educational Technology in the Science Classroom

Flick and Bell (2000) propose the following guidelines for technology use in science classrooms:

1. Technology should be introduced within science content.
2. Technology should address worthwhile science with appropriate pedagogy.
3. Technology instruction in science should take advantage of the unique features of technology.
4. Technology should make scientific views more accessible.
5. Technology instruction should develop students' understanding of the relationship between technology and science.

Today, technology as a teaching tool is influencing the way students learn. Technology for learning might include a variety of digital technologies that can open new options for students to learn science. Digital technologies have influenced science teaching in three areas (Flick & Bell, 2000). First, digital technologies have impacted science education K–16 by changing the ways in which interactions between teachers and students occur. Socially and psychologically, digital technologies influence the ways in which information is imparted, related, and organized. A second area of impact is the influence on instructional approaches that are driven by NSES and National Educational Technology Standards (International Society for Technology in Education [ISTE], 2008), both of which advocate the use of a range of digital technologies in teaching. Third, students and teachers are interacting with digital technologies in new and interesting ways on personal levels, as well as to conduct activities or deliver course content (teaching, advising, counseling, and mentoring) with the use of online discussions, Facebook, blogs, Second Life, Twitter, email, Glogster, Edmodo, GPS, texting, and others. These technological applications change rapidly.

It is not our intent to discuss all the possibilities for using educational technology in your science classroom. Nevertheless, we will include technology applications and tech connects like the following throughout the book.

TECH CONNECT: Podcasts

Make an audio tour of an outdoor classroom. Have students make observations and pose questions about natural outdoor features you select for them (plants, nests, flowers, water features, etc.). Have them research the features, write a script, and take turns recording salient points of interest for their designated area using a microphone and computer. Download audio recordings and make a class Podcast. These can be downloaded and combined to create a guided tour of the outdoor classroom for other classes and visitors.

The versatility of computers and digital technologies are everyday tools for today's youth, the digital generation.

For instance, a technology application for a science investigation may incorporate the use of a GPS to record the locations where your students are taking water samples along the steam. The data will allow students to accurately plot all the data collection locations on a map. Mapping the locations give students visual data of all the locations that assists them in making sense of their findings. Using this approach, they might explore where within the watershed their sample sites are located or whether their sample site was on a straight stretch or on a bend in the steam, and use that information to determine patterns that might influence water quality. Another example is using Twitter as a way to communicate information between the team leaders at the different sample collection sites.

As a science teacher, you're in a unique position not only to use technologies to enhance learning, but also, when appropriate, to explain the science associated with the technology. However, don't be misled: technology is an application of science, but technology can advance on its own. We urge you to use technology because it enhances the students' abilities to learn, understand, and conduct science, and not use it simply for its own sake. Sometimes, simple discussions enhance learning far more effectively than a technological tool.

Elaborate

Finding the Nature of Science in Everyday Things

At this point, you should be familiar with the basic principles of the nature of science. During the fossil activity you experienced some of the nature of science tenets (perhaps without even realizing it). In this task, we ask you to apply what you have learned about the nature of science. Read the following excerpt from a book by the late physicist Richard Feynman, and identify as many tenets of the nature of science as you can.

What principles did you find evidence for in Feynman's story? Did you find aspects of the nature of science that represent the notion that science is amoral? Did you find aspects of the nature of science that science is empirical? Did you find evidence that there are multiple approaches to conducting science? What other tenets are found in the story? Which of the principles seem most common in the story?

From "WHAT DO YOU CARE WHAT OTHER PEOPLE THINK?": FURTHER ADVENTURES OF A CURIOUS CHARACTER by Richard Feynman as told to Ralph Leighton. Copyright@1988 by Gweneth Feynman and Ralph Leighton. Used by permission of W. W. Norton & Company, INC., pp. 12–16.

◆ ◆ ◆

Before I was born, my father told my mother, "If it's a boy, he's going to be a scientist." When I was just a little kid, very small in a highchair, my father brought home a lot of little bathroom tiles—seconds—of different colors. We played with them, my father setting them up vertically on my highchair like dominoes, and I would push one end so they would all go down.

Then after a while, I'd help set them up. Pretty soon, we're setting them up in a more complicated way: two white tiles and a blue tile, two white tiles and a blue tile, and so on. When my mother saw that she said, "Leave the poor child alone. If he wants to put a blue tile, let him put a blue tile."

But my father said, "No, I want to show him what patterns are like and how interesting they are. It's a kind of elementary mathematics." So he started very early to tell me about the world and how interesting it is.

We had the *Encyclopaedia Britannica* at home. When I was a small boy he used to sit me on his lap and read to me from the *Britannica.* We would be reading, say, about dinosaurs. It would be talking about the *Tyrannosaurus rex*, and it would say something like, "This dinosaur is twenty-five feet high and its head is six feet across."

My father would stop reading and say, "Now let's see what that means. That would mean that if he stood in our front yard, he would be tall enough to put his head through our window up here." (We were on the second floor.) "But his head would be too wide to fit in the window." Everything he read to me he would translate as best he could into some reality.

It was very exciting and very, very interesting to think there were animals of such magnitude—and that they all died out, and that nobody knew why. I wasn't frightened that there would be one coming in my window as a consequence of this. But I learned from my father to translate: everything I read I try to figure out what it really means, what it's really saying.

We used to go to the Catskill Mountains, a place where people from New York City would go in the summer. The fathers would all return to New York to work during the week, and come back only for the weekend. On weekends, my father would take me for walks in the woods and he'd tell me about interesting things that were going on in the woods. When the other mothers saw this, they thought it was wonderful and that the other fathers should take their sons for walks. They tried to work on them but they didn't get anywhere at first. They wanted my father to take all the kids, but he didn't want to because

(Continued)

(Continued)

he had a special relationship with me. So it ended up that the other fathers had to take their children for walks the next weekend.

The next Monday, when the fathers were all back at work, we kids were playing in a field. One kid says to me, “See that bird? What kind of bird is that?”

I said, “I haven’t the slightest idea what kind of bird it is.”

He says, “It’s a brown-throated thrush. Your father doesn’t teach you anything!”

But it was the opposite. He had already taught me: “See that bird?” he says. “It’s a Spencer’s warbler.” (I knew he didn’t know the real name.) “Well, in Italian it’s a *Chutto Lapittida*. In Portuguese, it’s a *Bom da Peida.* In Chinese, it’s a *Chung-long-tah,* and in Japanese, it is a *Katano Tekeda.* You can know the name of that bird in all the languages of the world, but when you’re finished, you’ll know absolutely nothing whatever about the bird. You’ll only know about humans in different places, and what they call the bird. So let’s look at the bird and see what it’s *doing*—that’s what counts.” (I learned very early the difference between knowing the name of something and knowing something.)

He said, “For example, look: the bird pecks at its feathers all the time. See it walking around pecking at its feathers?”

“Yeah.”

He says, “Why do you think birds peck at their feathers?”

I said, “Well, maybe they mess up their feathers when they fly, so they’re pecking them in order to straighten them out.”

“All right,” he says. “If that were the case, then they would peck a lot just after they’ve been flying. Then, after they’ve been on the ground a while, they wouldn’t peck so much any more—you know what I mean?”

“Yeah.”

He says, “Let’s look and see if they peck more just after they land.”

It wasn’t hard to tell: there was not much difference between the birds that had been walking around a bit and those that had just landed. So I said, “I give up. Why does a bird peck at its feathers?”

“Because there are lice bothering it,” he says. “The lice eat flakes of protein that come off its feathers.”

He continued, “Each louse has some waxy stuff on its legs, and little mites eat that. The mites don’t digest it perfectly, so they emit from their rear ends a sugar-like material, in which bacteria grow.”

Finally he says, “So you see, everywhere there’s source of food, there’s *some* form of life that finds it.”

Now, I knew that it may not have been exactly a louse, that it might not be exactly true that the louse’s legs have mites. That story was probably incorrect in *detail*, but what he was telling me was right in *principle*.

Another time, when I was older, he picked a leaf off a tree. This leaf had a flaw, a thing we never look at much. The leaf was sort of deteriorated; it had a little brown line in the shape of a C, starting somewhere in the middle of the leaf and going out in a curl to the edge.

“Look at this brown line,” he says. “It’s narrow at the beginning and it’s wider as it goes to the edge. What this is, is a fly—a blue fly with yellow eyes and green wings has come and laid an egg on this leaf. Then, when the egg hatches into a maggot (a caterpillar-like thing), it spends its whole life eating this leaf—that’s where it gets its food. As it eats along, it leaves behind this brown trail of eaten leaf. As the maggot grows, the trail grows wider until he’s grown to full size at the end of the leaf, where he turns into a fly—a blue fly with yellow eyes and green wings—who flies away and lays an egg on another leaf.”

Again, I knew that the details weren’t precisely correct—it could have even been a beetle—but the idea that he was trying to explain to me was the amusing part of life: the whole thing is just reproduction. No matter how complicated the business is, the main point is to do it again!

Not having experience with many fathers, I didn’t realize how remarkable he was. How did he learn the deep principles of science and the love of it, what’s behind it, and why it’s worth doing? I never really asked him, because I just assumed that those were things that fathers knew.

> My father taught me to notice things. One day I was playing with an "express wagon," a little wagon with a railing around it. It had a ball in it, and when I pulled the wagon, I noticed something about the way the ball moved. I went to my father and said, "Say, Pop, I noticed something. When I pull the wagon, the ball rolls to the back of the wagon. And when I'm pulling it along and I suddenly stop, the ball rolls to the front of the wagon. Why is that?"
>
> "That, nobody knows," he said. "The general principle is that things which are moving tend to keep on moving, and things which are standing still tend to stand still, unless you push them hard. This tendency is call 'inertia,' but nobody knows why it's true." Now, that's a deep understanding. He didn't just give me the name.
>
> He went on to say, "If you look from the side, you'll see that it's the back of the wagon that you're pulling against the ball, and the ball stands still. As a matter of fact, from the friction it starts to move forward a little bit in relation to the ground. It doesn't move back."
>
> I ran back to the little wagon and set the ball up again and pulled the wagon. Looking sideways, I saw that indeed he was right. Relative to the sidewalk, it moved forward a little bit.
>
> That's the way I was educated by my father, with those kinds of examples and discussions: no pressure—just lovely, interesting discussions. It has motivated me for the rest of my life, and makes me interested in *all* the sciences. (It just happens that I do physics better.)
>
> I've been caught, so to speak—like someone who was given something wonderful when he was a child, and he's always looking for it again. I'm always looking, like a child, for the wonders I know I'm going to find—maybe not every time, but every once in a while.
>
> From "WHAT DO YOU CARE WHAT OTHER PEOPLE THINK?": FURTHER ADVENTURES OF A CURIOUS CHARACTER by Richard Feynman as told to Ralph Leighton. Copyright@1988 by Gweneth Feynman and Ralph Leighton. Used by permission of W. W. Norton & Company, INC.

Evaluate

Nature of Science in the News

Feynman's narrative illustrates many examples of the nature of science. Now we want you to identify some on your own. Focusing on global climate change, you will use resources and technologies to locate information (i.e., news articles, journal articles, websites, and other resources) to illustrate the nature of science. Find three different sources of information to demonstrate three different the nature of science tenets (see pages 8–10). Identify the source of information and describe how it depicts global climate change. Then explain how the information typifies the nature of science tenet you select. For example, you might locate a newspaper article that *describes* how scientists are designing and testing huge reflective sheets of plastic to lay down over large areas of the polar ice caps. The researchers hypothesize that the sheets will decrease or eliminate the rate of melting. You *decide* that the newspaper article represents science as a "creative endeavor" and *explain* how this aligns with the tenet selected. In this case, you begin by stating that the scientists creatively used knowledge of the properties of inexpensive materials to design a potentially useful technology for slowing down the melting of the ice caps due to global climate change.

Summary

As you began this chapter, we asked you to consider what "science" means to you. Do you still think of science as mostly experiments? Do you think of science as concepts and terms students must memorize? Do you see science as a fixed sequence of steps that scientists and students use to carry out an experiment? Did reading the chapter challenge some of your ideas about science? We hope so. A major goal of K–8 teachers of science is to foster the development of students who are able to make informed decisions about science that influences their lives. This is referred to as "scientific literacy." You will not be able to accomplish this goal in a single year, but you can begin this journey by teaching students about the nature of science and the use of technologies, as well as by teaching them the skills for investigating science via inquiry. In closing, this chapter addressed science as a body of knowledge, a process or method, and a way of knowing the natural world. The nature of science as a way of knowing was emphasized in this chapter because it is the most neglected of these aspects in teaching science. Your task as a K–8 science teacher is to teach all aspects of science. Furthermore, these aspects of science should be continually addressed throughout the K–12 curriculum (AAAS, 1993; NRC, 1996).

Annotated Resources

University of California's Museum of Paleontology

http://evolution.berkeley.edu/evosite/nature/index.shtml

This website was created by the University of California's Museum of Paleontology with support provided by the National Science Foundation and the Howard Hughes Medical Institute. It is an excellent resource for both teachers and students. The site explores the nature of science with an interactive quiz to challenge your abilities to draw on your knowledge of the nature of science. For teachers, this site includes a variety of excellent grade level activities that can be used in K–8 science classrooms to teach the various tenets of the nature of science.

American Association for the Advancement of Science website has free online access for the book. *Science for All Americans* (AAAS, 1991)

http://www.project2061.org/publications/sfaa/online/chap1.htm

This website provides a chapter on the nature of science and inquiry, which is appropriate reading for teachers. It provides further examples and insights into a scientific worldview, the nature of science, and the scientific enterprise. Chapter 1 points out key ideas about scientific knowledge and the scientific endeavor which form the requisites for scientific literacy.

Nature of Science Podcasts

http://vmsstreamer1.fnal.gov/VMS_Site_03/Lectures/NOSPodcasts/

This website offers a number of Podcasts with eight early-career scientists from a variety of different science disciplines working at the University of Chicago or at the Fermilab in Chicago. These Podcasts put a human face on scientists who talk about what it is like to be a scientist and what science is. They talk about science and its role in controversies such as evolution and the Big Bang Theory. They also discuss what it is that makes science so exciting in the work they do as scientists. These Podcasts are easy to use and can be listened to using iTunes or another MP3 device.

International Society for Technology in Education

http://www.iste.org/

This website is for technology educators, teachers, and administrators. The site provides the National Educational Technology Standards (NETS) and performance indicators for students, teachers, and administrators. You will also find articles and books related to educational technology on the website.

Great Fossil Find (by Randak and Kimmel)

http://www.indiana.edu/~ensiweb/lessons/gr.fs.fd.html

This is a website with a variation of the explore phase activity used in the chapter. The activity on this website is appropriate for upper-elementary and middle school students.

American Museum of Natural History

http://www.amnh.org/ology/index.php?channel=paleontology#channel

This website is colorful and informative, and has hours of exploration embedded within. The site has a wide age-level appeal with information including fossil hunting, exploring timelines, interviews with a Protoceratops, and exploring a contemporary dig in the Gobi Desert with scientists. Students of all ages will find this site a delightful learning experience. This is an excellent site for teachers emphasizing inquiry, the nature of science, and content areas across several disciplines.

American Institute of Physics. (1997). *The best of wonderscience: Elementary science activities.* New York: Delmar Publishers.

This is an inquiry-based activity book rich in physical science activities. Activities target fourth- to eighth-grade students. Materials needed to conduct the activities are inexpensive and easy to locate for purchase. Some background information accompanies the units.

Assessing scientific inquiry by Erin Peters in *Readings in Science Methods, K–8.* Arlington, VA: National Science Teachers Association. 2008.

This short article discusses the elements of the nature of science and its ways of knowing as well as process skills involved with inquiry. It provides useful approaches to the assessment of inquiry with peer-reviewed sample questions, rubrics, and student products.

Annenberg Media Learner.org

http://www.learner.org/resources/series129.html?pop=yes&pid=1452

The website has a range of videos on a variety of issues related to science teaching and learning. The inquiry-based science workshop (Series 129) shows inquiry teaching and learning with practicing teachers and students within their K–8 classrooms. This one-hour video highlights teachers using inquiry to enhance student learning. This video workshop is useful for preservice and practicing teachers exploring the inquiry process and how that process benefits students, and provides teachers with strategies to use within the classroom.

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