Ninth Edition

Teaching Children SCIENCE

A Discovery Approach

Donald A. DeRosa
Joseph Abruscato

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Preface

About the Authors

Don DeRosa, Ed.D., is a clinical associate professor at Boston University School of Education, where he teaches science teaching methods to elementary and secondary education pre-service teachers.

Joseph Abruscato was a nationally prominent educator and author of professional books in the field of science teaching. He retired from The University of Vermont in 2006 with the rank of Professor Emeritus after a distinguished career that began there in 1969. Joe received his B.A. and M.A. degrees from Trenton State College in science education, physics and chemistry and his Ph.D. in science education and curriculum development from The Ohio State University. At The University of Vermont, Joe was the chief architect of enhancing the Elementary Teacher Preparation Program with articulated campus-based pedagogy and public school practica.

About this Book

Teaching Children Science was written with the K—5 pre-service elementary teacher in mind. The authors understand that teaching science may be out of the comfort zone for many readers. A primary goal of the text is to help aspiring elementary teachers understand their roles not as science experts, but as lead learners of science who can inspire and guide their young students to experience science through the joys and challenges of inquiry and discovery. It emphasizes methods and strategies for teaching the subject that invite students to learn science through doing science. Practices are grounded in theory that reflects research about how students learn science and scientific ways of thinking. Effective science teaching requires a familiarity with science practices and content as well as strategies and methods. Chapter 1, *Inquiry: The Path; Discovery: The Destination*, begins with some insights about what it means to do science and the nature of science. Chapters 7–12 are devoted specifically to providing fundamental content knowledge in the Earth/space, life, and physical sciences for the elementary school teacher.

New to This Edition

- **Expanded coverage of (and alignment to) NGSS Standards**

As the Next Generation Science Standards become more embedded in the national curricula, evidence and resources that inform effective three-dimensional teaching and learning continue to emerge. This text addresses each science practice and incorporates resources to support three-dimensional instructional strategies.

- NGSS curriculum bundles are addressed in Chapter 3, and evidence statements are used to support three-dimensional assessment in Chapter 5.
- Strategies for culturally responsive teaching based on NGSS Appendix D, "All Standards, All Students," are included in Chapter 3. You will also find references of NGSS to Common Core State Standards in Chapter 2.

- Sample lessons and activities throughout the text model the integration of science practices, disciplinary core ideas, and crosscutting concepts.
- The content in Chapters 7–12 and the ideas for putting content into action in Appendices A, B, and C are organized around NGSS Disciplinary Core Ideas.

Revised chapter on planning now focuses on the 5E learning cycle

The 5E learning cycle, developed by the Biological Science Curriculum Studies in the late 1980s, continues to be the basis for concept development in lesson planning strategies reflected throughout the text. More examples of hook questions for engagement are provided as well as a lesson plan template with explicit guidelines for developing lessons that incorporate criteria for the "Engage, Explore, and Explain" phases of the 5E instructional strategy in Chapter 3.

Reorganized and condensed chapters provide a more streamlined learning experience

- The text has been reduced from 18 to 12 chapters and organized into two parts rather than four. Part 1 addresses science teaching theory and practice, while Part 2 provides a refresher of science content knowledge in the areas of Earth/space sciences, life sciences, and physical sciences.
- Previous edition chapters on using technology and adapting the curricula have been eliminated, and the information presented in these chapters has been integrated throughout the book. For example, in Chapter 3, Sheltered Instruction Observation Protocol (SIOP) has been coupled with elements of the 5E instructional strategy to illustrate accommodations for English language learners. In Appendix A, students are directed to access and analyze data on the latest earthquake activity across the globe provided by the United States Geological Survey to explore the dynamics of plate tectonics.
- Previous edition Chapters 12, 15, and 18 have moved to Appendices A, B, and C. These sections include suggested ideas and activities for implementing content in Chapters 7–12. Ideas for each content area—Earth/space sciences, life sciences, and physical sciences—are organized as follows:
  - **Unit Plan Ideas and Questions:** These are organized by the Disciplinary Core Idea Arrangements of the NGSS and include a unit title, question, and brief unit overview.
  - **Make the Case—An Individual or Group Challenge:** This section challenges the reader to reflect on the use of phenomena in three-dimensional teaching and identify potential phenomena for disciplinary core ideas.
  - **Classroom Enrichment Ideas:** This section makes suggestions for discovery centers, bulletin boards, and field trips that could enrich each content area. Suggestions for articulation with disciplinary core ideas are listed in parenthesis for each enrichment idea.
  - **Examples of Topics and Phenomena:** Suggested phenomena are given for selected topics in each discipline along with motivating questions, activities, and science content that support the topic for teachers.

- **Discovery Activities:** These are activities that you may find helpful to support teaching the content area. Each activity includes objectives, science processes, materials, a motivation (engagement), directions, discussion questions, and science content for the teacher.

Real Teaching vignettes provide insight and reflection on practices

Included in each content chapter (7, 9, 11 and 12), these vignettes describe real lessons taught or observed by the author. The narratives include brief reflections about the teaching moves and decisions made by the teacher during the class. Bracketed references to instructional strategies addressed in the text are also included. The examples are meant to illustrate actual teaching "episodes," with the hope that readers will learn from these small victories and failures! See *Real Teaching: Air Pressure* in Chapter 11.

Key Content Updates by Chapter

- Chapter 1, previously Chapters 1–2, provides updates with more depth on key topics such as how children learn science, the nature of science, and an introduction to the NGSS as essential resources for science educators.
- Chapter 2 addresses each of the science practices in much more depth than the prior edition as well as the role of inquiry and discovery in science learning with sample activities that illustrate inquiry skills.
- Chapter 3 addresses planning learning experiences for children based on relevance, rigor, and coherence utilizing resources such as the NGSS bundles and Understanding by Design to guide unit planning. Elements of the 5E instructional strategy are used as frameworks for organizing science lessons that emphasize scientific ways of knowing. A sample lesson is included that illustrates lesson design using NGSS resources. Universal Design for Learning and Response to Intervention are included for consideration in lesson planning. Lesson plan templates, new to this edition, provide scaffolds for pre-service teachers to develop lesson plans that inspire scientific explanations and solutions to problems.
- Chapter 4, *Creating Environments for Discovery*, addresses more nuanced strategies for creating dynamic science learning experiences, ranging from the physical work space and discovery stations to an in-depth discussion about fostering accountable science talk through effective questioning, talk-tools, and science circles.
- Chapter 5 focuses on assessing across three dimensions with examples based on NGSS assessment tasks and evidence statements. Both formative and summative assessment strategies are addressed, including traditional and reform-based assessments such as science notebooks, student interviews, and portfolios. As in the previous edition, examples of analytical and holistic rubrics are provided.
- Chapter 6 addresses integration of science and engineering with other disciplines. New to this edition are discussions about STEAM in the context of integration.
- Chapters 7, 9, 11 and 12 provide a refresher of science content knowledge and have been updated and aligned with disciplinary core ideas. Sections referred to as *Real Teaching* have also been included in content chapters. *Real Teaching* consists of selected reflections by the author on his

experiences teaching concepts in the discipline to elementary children. References to teaching strategies introduced in Chapters 1–6 are bracketed to illustrate how the strategy may be implemented in practice.

Instructor Resources

The following supplements to the textbook are available for download under the "Educator" tab at www.pearsonhighered.com. Enter the author, title, or ISBN, then select this textbook. Click on the "Resources" tab to view and download the supplements detailed below.

- **Instructor's Resource Manual with Test Bank**

  The Instructor's Manual/Test Bank (0-13-474292-3) provides activity ideas for class sessions as well as multiple-choice quizzes.

- **PowerPoint™ Presentations**

  Ideal for lecture presentations or student handouts, PowerPoint™ Presentations (0-13-474284-2) for each chapter include key concept summaries.

Acknowledgments

Many people have shaped this book's content, directly and indirectly. Most of all, I would like to acknowledge Joseph Abruscato, who passed away in 2009. Joseph was a gifted educator whose contributions to the field of science education have undoubtedly informed and inspired generations of teachers and students. He is responsible for the quality and success of this text and several other publications of which he is the author. It is with humility that I assume responsibility for carrying on the legacy of his wonderful work.

I would like to thank those who have reviewed this edition of *Teaching Children Science* for sharing their expertise and valuable insights: Audrey Cohan, Ed.D., Molloy College; Sarah J. Carrier, NC State University; Todd F. Hoover, Bloomsburg University of Pennsylvania; Joe Sciulli, University of North Carolina at Pembroke; John D. Tiller, Tennessee State University.

Finally, I would like to thank Drew Bennett, Jill Ross, Heather Winter, and Yagnesh Jani for their patience, guidance, and attention to the details of this book.

D. D.

PART one

Strategies and Techniques

The roar of waves crashing on a beach; the careful maneuvering of a brightly colored ladybug, making its way through branches and leaves, touching, smelling, and tasting all in its path; and the first dark, belching breaths of a volcano coming to life after being dormant—all are parts of the natural world in which we live.

Wanting to make sense of that world is a powerful drive that leads us humans to inquire, to discover, and, ultimately, to understand. To empower children to be able to inquire, discover, and understand—not just now but throughout their lives—is the greatest challenge we teachers face. To teach children science is to meet that challenge head on.

Now I might be wrong, but my guess is that you are not very confident about teaching children science. You may fear that science will be difficult for children to understand and that it will provoke questions that will be hard for you to answer. You may also think that science time will be a period of utter chaos and confusion, as liquids bubble out of beakers and chemicals flash, pop, and bang.

It is my hope that most of you have had wonderful experiences in science and that you will share the thrill of discovery with your students. On the other hand, perhaps your encounters with science have emphasized the memorization of facts, formulas, and vocabulary that made science boring and tedious. If so, I deeply regret that you did not experience science. I hope that you will come to know science as a journey of adventure and discovery that you can share with your students.

Now, the phrase *doing science* may elicit a range of images. As you will find out, there is no single way to do science. You may even think that doing science is beyond the ability of your elementary students and that they need to learn vocabulary and theories before they can practice science. I hear this sentiment often. But it does not make sense. Imagine if children learning to play soccer or play the violin were given books to study the rules, history, and techniques of soccer or music. Think of what it would be like if practices consisted of lectures, reviews, and videos of "real" soccer games or violin recitals. How many of those children do you think would want to play soccer or the violin? What are the chances that any of them would pursue a career in soccer or music? On the other hand, if we give 5-year-olds a ball and put them on a soccer field (it may not be pretty) or let a child run a bow across the violin strings (it won't sound great), then they are much more likely to be inspired to learn the rules, strategies, theory, and techniques associated with soccer and music as they grow toward being accomplished athletes or musicians. Introducing young children to science is no different. Science is an *active* way of knowing that engages the body and brain. Your job is to engage the students in science practices while they grow in their knowledge of science concepts. They won't look or act like pros for a long time, but the first step on the journey is the opportunity to get on the field.

My goal with this book is to help you along the path to becoming enthusiastic teachers who have the knowledge and confidence to put their students on the playing field of science. But first you must experience the joy of science. If you enjoy teaching science, then your students will be inspired to learn science, and have fun along the way.

Part One of this text will help prepare you to meet that challenge. To be sure, there is much to know! How do children learn, and what can you do to enhance their learning? How can you help them learn the science practices and inquiry process skills to make sense of the world using accurate scientific knowledge? What should you teach (as well as what not to teach) and what is the best way to teach it for your students? What are the national trends that guide the science content and practices children are expected to learn? How can you plan meaningful lessons and manage an inquiry-based classroom? How can you make good use of the valuable resources of the Internet? How can you integrate science with other subject areas? And how can you respect diversity and ensure equity so that *all* your students have the best opportunities to succeed? Throughout all of this, you need to know how and when to assess children's progress and respond in meaningful ways that advance their knowledge.

The chapters in Part One (Chapters 1–6) address these questions. In completing them, you will build a foundation of general knowledge about teaching children science. You can add the **specific pedagogical content knowledge** and skills related to the Earth/space, life, and physical sciences, through the chapters in Part two. Lesson ideas have been moved to the Appendix. They include starter ideas to engage students, activities in each discipline that inspire inquiry, demonstrations, in-class learning centers, field trips, and bulletin board material. I encourage you to use this book in a manner that fits your needs. Some students prefer to go directly to the content in Part Two and refer back to the theory in Part One as needed. Other students opt to familiarize themselves with the theory first and then put it in practice. You may opt to go directly to the activities in the appendix.

Yes, it's a lot to learn!

The truth is, becoming an okay teacher isn't too difficult. But becoming a truly excellent teacher takes focus and determination. That's what you and I will be working toward throughout this text!

CHAPTER 1

Inquiry: The Path; Discovery: The Destination

It is not just teaching science,
it is using science to teach thinking.

Vasilyev Alexandr/Shutterstock

Learning Objectives

After completing the activities in this chapter, you should be able to:

1.1 Develop a working definition of science.

1.2 Describe how research about learning science informs science teaching.

1.3 Describe the purpose and three dimensions of the Next Generation Science Standards.

▶ GETTING STARTED

In order to teach science, it is important that we reflect on how we understand science and what scientists do. This chapter will start us thinking about science and look to the Next Generation Science Standards as a resource that informs and guides the content of our science teaching. We will also consider research about how students learn science that informs our teaching.

Science: What Is It, Really?

Before we begin to think about teaching science, let's pause to think about what science means. We all probably have some notion, based on our prior experiences and knowledge, of what scientists do. Perhaps some of you know scientists or are scientists yourselves. Maybe you have read about people making scientific discoveries, or perhaps you have a vision of science provided by the media. In any case, suppose you were asked by non-scientist friends, "What is science? What do you teach when you teach 'science'?"

Settling on a precise definition of science is not so easy, even among the science community. Here are some ways organizations and scientists have described science.

"Science is more than a body of knowledge. It is a way of thinking; a way of skeptically interrogating the universe with a fine understanding of human fallibility.[1]—Carl Sagan

Some key themes can be identified in these definitions:

- Science is a process—it is a pursuit, practical activity, application
- Science is a way of knowing—understanding/explaining the natural world
- Science is systematic—use of methods to the process of seeking explanations and making sense of the world
- Science is knowledge—the principles, laws, and theories that explain the natural world

Note that science is active. It is an endeavor that seeks knowledge—knowledge pursued in a systematized way. Unfortunately, science is often associated solely with its outcomes or a body of knowledge. This is tantamount to skipping a movie and watching only the final scene. The ending does not make sense if you do not know the plot. When science is presented as only facts and answers, it ceases being science. Anyone with access to the Internet can find information. Science involves the process of generating explanations based on evidence and logic. Scientists rarely have answers. If they did, they would not need to practice science. Similar to Jean Piaget's quote, "Intelligence is what you use when you don't know what to do," I like to think of science as knowing what to do when you do not have an answer. Science is a systematic search with a variety of strategies that results in a dynamic body of scientific knowledge. Most important to remember is that science is a way of knowing that uses *evidence* supported by logical reasoning to help us make sense of the world.

As an elementary school science teacher, you will teach practices, values, and attitudes associated with seeking scientific explanations as well as core ideas and principles that support current scientific explanations of natural phenomena (see Table 1.1).

What Is Scientific Thinking? A Look at Some Masters

Great thinkers such as Einstein, Galileo, and da Vinci had the ability to create detailed mental models. We all create mental models to some extent. When we can "see" or "picture" a situation in our minds, we can often understand and explain it better. Expressions such as "I see what you mean" and "It is like . . . " suggest this tendency to create mental models. Great thinkers have the extraordinary ability

Table 1.1 Examples of science as a body of knowledge, as a process, and values

Body of Knowledge

- Energy can change form.
- Matter can change form.
- The total amount of matter and energy in the universe never changes.
- For every action, there is an equal and opposite reaction.
- Like poles of magnets repel each other.
- Unlike poles of magnets attract each other.

Inquiry Process Skills

- Descriptive modeling
  - Questioning
  - Observing
  - Enumerating
  - Classifying
  - Measuring
  - Comparing
  - Communicating
- Explanatory modeling
  - Questioning
  - Hypothesizing
  - Inferring
  - Interpreting data
  - Communicating
- Experimental modeling
  - Questioning
  - Predicting
  - Identifying variables
  - Controlling variables
  - Controlling experiments
  - Communicating

Values and Attitudes Associated with Scientific Inquiry

- Skepticism
- Criticism
  - Ability to criticize
  - Acceptance of criticism
- Cooperation
- Persistence
- Freedom to think originally

to create and keep complex mental models of a system in their mind and imagine what would happen when variables in the models interact in novel ways. For example, Einstein could imagine what would happen when someone rode a beam of light, and da Vinci could imagine the miracle of flight. As educators, we need to teach our students the cognitive skills necessary to create mental models and to create a culture of thinking in which these cognitive skills become habits of mind. Habits of mind take years to develop; they cannot be covered in a lesson or two. The habits of good, scientific thinking must become a conscious part of the culture of learning; children need to be made aware of their thinking strategies when they are thinking scientifically.

Doing Science and the Next Generation Science Standards

One of the principles specific to science teaching and learning suggested by the National Academies of Science is not only teaching what scientists know, but how they know.[2]

You may recall reading about the scientific method in textbooks. It usually read something like the following: Ask a question, form a hypothesis, make a prediction, test the prediction, analyze results, make a conclusion. While these components may be associated with science practice, there is much more to doing science. Solving problems and seeking explanations is a messy business, often fraught with uncertainty. Doing science means taking wrong turns, encountering road blocks, doubling back, and trying alternate paths that inform the next turn. It requires imagination and creativity to think about explanations and solutions in novel ways. By acknowledging uncertainty and purposefully designing instruction through which students encounter uncertainties that challenge their understanding, we can foster the development of cognitive tools that will help students seek explanations and solve problems.[3] When we teach students science, we teach them to use observation, reasoning, creativity, and imagination to think in ways that are new for them and lead them to personal discoveries and deeper understandings. In the words of Freeman Dyson,[4] "All of science is uncertain and subject to revision. The glory of science is to imagine more than we can prove."[5]

Scientists use a variety of practices when they do science. Practices include the use of both skills and knowledge. Eight science practices have been identified in the Next Generation Science Standards (NGSS).[6, 7] These standards were developed by teams of scientists and educators to identify what students in grades K through 12 should know and be able to do upon completion of each grade with respect to science and engineering. The NGSS will be introduced in more detail in Chapter 2 and referenced throughout the text. The eight practices are as follows:[8]

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

Practicing science and learning core scientific concepts go hand in hand. Scientists and science learners both seek to make sense of the world as they encounter new information and discover relationships. Therefore, the NGSS also identify core ideas and cross-cutting concepts be taught along with the science practices. Disciplinary core ideas are scientific principles and concepts that support explanations in science and problem solving in engineering. Disciplinary core ideas are grouped in four domains: the physical sciences; the life sciences; the Earth and space sciences; and engineering, technology, and applications of science.

Crosscutting concepts are the big ideas common across the domains of science and engineering: Patterns; Cause and effect; Scale, proportion, and quantity; Systems and system models; Energy and matter; Structure and function; Stability and change. The crosscutting concepts help students organize ideas and make connections across disciplines.[9]

The integration of these science practices, disciplinary core ideas, and crosscutting concepts in science teaching is known as three-dimensional instruction when they are used together by students to make sense of phenomena.

As with content standards in general, the NGSS do not dictate or instruct about how to teach. They address what students should know and be able to do in a content area by the end of a particular grade. It is important to note that the authors of the NGSS recognize that science and engineering cannot and should not be taught in isolation. This is particularly the case in elementary school, which puts an emphasis on language arts and math. Therefore, the NGSS include connections to the Common Core State Standards (CCSS), which is an educational initiative that details what K–12 students should know in English language arts and mathematics at the end of each grade. No doubt you are or soon will be familiar with the CCSS through methods courses you take in math and language arts. We will consider articulation of the CCSS with science education throughout this text.

There are many excellent resources available on the NGSS website to support the understanding and implementation of the standards. The resources continue to grow on a regular basis as the science education community becomes more familiar with the standards. In fact, the resources can be a bit overwhelming at first glance. It will take some time for you to become familiar with them. This may be a good time to visit the NGSS site and get to know the standards. Go to http://www.nextgenscience.org/. Scroll down and view the introductory video. Several of the resources will be embedded as they apply throughout this text.

How Children Learn Science

> *"Be very, very careful what you put into that head, because you will never, ever get it out."*
>
> —Cardinal Wolsey (1475?–1530)

Research in the past decade has forced us to rethink traditional views of how children learn science. This is not to suggest that theories put forth by people like Jean Piaget and Jerome Bruner are not important. Piaget's cognitive theories described stages of development with increasingly complex schemas. Bruner recognized the import and power of the individual's own discovery and progressive construction of knowledge through a spiraling curriculum that reinforced and advanced prior learning in a deliberate manner. While Piaget was concerned with cognitive development, Bruner was concerned with teaching and learning. He suggested that children should not be limited by predetermined developmental stages, but that any subject can be taught effectively in an intellectually honest way if taught appropriately for the developmental level.[10] There is variation among children in their capacity to think and understand at higher levels of thinking. We know that we can help children develop capacities to think and learn by providing stimulating and thoughtful learning experiences. Carl Wieman, Nobel Prize winner in physics and director of the Carl Wiemen Science Education Initiative at the University of British Columbia, sums up how people learn in the following statement: "Much of educational and cognitive research can be reduced to this basic principle: People learn by creating their own understanding. Effective teaching facilitates that creation by engaging students in thinking deeply about the subject at an appropriate level and then monitoring that thinking and guiding it to be more expert like."[11]

In 2005 the National Academies of Science published *How Students Learn: History, Mathematics, and Science in the Classroom.*[12] The publication was the result of work by committees created to study developments in the science of learning. The following three principles that emerged from the study inform how we should think about learning science:[13]

- Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.
- To develop competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.
- A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

Let's unpack each of these principles.

1. Students come to the classroom with preconceptions about how the world works. Each student brings unique understandings based on a host of variables influenced by family, culture, race, ethnicity, socioeconomics, religion, gender, and geography. If their initial understanding is not engaged, they may fail to grasp the new concepts and information, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.

Children come to us with a wealth of ideas about how the world works. Their understanding is based on the evidence and the contexts in which they experience the world. Knowledge of student preconceptions provides a starting point for teaching. Campbell et al. suggest that student preconceptions act as stepping stones for children to make sense of the world.[14] Discourse and activities wherein students' preconceptions are challenged compel them to address their preconceptions and either modify or replace them.

Suppose, for example, that Juan enters class believing Earth is flat, which makes sense to Juan because all the evidence from his experience suggests a flat Earth. When Juan is told that Earth is round (in fact, the Earth is spherical), he is reluctant to let go of his flat-Earth notion. In order to reconcile his prior belief that Earth is flat with the new information, he creates a mental model of a pancake-shaped Earth that fits both with his prior understanding of a flat Earth and with the new information that Earth is round.[15] Cognitive psychologists use the term *assimilation,* a term also used by Jean Piaget to describe how we combine new experiences with existing ideas that may support or deepen but do not change our fundamental understanding.

Suppose, however, that Juan observes ships sailing over the horizon that do not fall off the edge of Earth. When challenged to explain this phenomenon, he cannot reconcile it with his current mental model of a flat Earth. He is faced with the choice of either having to reject the evidence or accommodate his mental model to one of a spherical Earth. When new evidence cannot be reconciled with prior understanding, mental models are forced to change, resulting in a new rather than simply revised schema. Replacement of an extant schema with a new one is accommodation, also described by Jean Piaget. Assimilation and accommodation are not mutually exclusive. They often complement each other in the learning process.

2. To develop competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.[16]

   This principle speaks to a tension between facts and big ideas. Science education has been characterized by memorization of facts. Generally, rote memorization is one of the least efficient learning strategies. One of my undergraduate students recently wrote in a reflection that "it was almost like a chore to have to memorize all of the new ideas" she was learning in her science classes. I wrote back that, "It is unfortunate that you had to memorize ideas, rather than those ideas being memorable because they were meaningful." It is difficult to make sense of facts apart from a meaningful context. Principle 2 suggests that in order to be an effective inquirer, one must both know the facts and understand the concepts that connect the facts. For example, memorizing parts of the digestive system alone does not result in deep understanding or retention. But questioning the changes that take place as an apple passes through our digestive system creates a context that makes the structures and functions of the digestive system meaningful and logical. As science teachers, we can assist students in making connections of facts to concepts that help them make sense of the world.

3. A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.[17]

   Metacognition is a term that will not be familiar to our students, but one that we need to think about and allow to inform our teaching. Metacognition in the context of teaching and learning is self-monitoring of one's learning. Simply stated, it is a self-awareness of the strategies that help us learn. For example, suppose a student is learning about characteristics and relationships among producers and consumers in a food web. She finds that organizing photos of plants and animals in categories of producers and primary, secondary, and tertiary consumers helps her learn the relationships among trophic levels. Another student finds that if he creates a story linking the organisms in a food web's trophic levels, then it makes sense to him. In both cases, students are aware of strategies that help them learn. Research suggests that experts in any discipline are able to ask themselves, "Do I understand this?" and "How can I check my understanding?"[18]

   We can foster student metacognition in the science classroom by creating opportunities for students to think about strategies that help them learn. Have students keep a science notebook in which they can write about what they learned and how they learned it as well as what confuses them. When students experience difficulty learning science, ask what they do when they do not understand, whether their strategy is working, and what they could do differently.

Good teaching of any discipline will consider these three basic principles. For those of us teaching science, we add another principle: Doing Science. Perhaps you are familiar with the saying that people learn by doing. Wieman noted that new graduate students in his physics lab are often clueless about how to proceed when faced with a research project, despite having been very successful undergraduate students. However, after working with knowledgeable researchers for a few years in the lab, the graduate students turn into experts. He suggests that this is because the students are "engaged in exactly the same cognitive processes required for developing expert competence."[19] Now, your elementary students are not learning at the same level as graduate physics students, and we do not expect them to be experts by the end of elementary school. But they, too, will learn how to inquire and construct knowledge if they are engaged in learning science principles and concepts while actively involved in the practices of science. Of course, they cannot do so without guidance provided by you, the teacher.

The Nature of Science

In order to understand and teach science, we need to consider values and beliefs associated with science. These are collectively referred to as the nature of science. Underlying the nature of science is the notion that science is a human endeavor.

Science is a very social process. Science advances through peer reviews that evaluate and critically assess claims based on evidence and reason. Explanations are based on varying degrees of certainty. In some cases, such as climate change and evolution, the evidence is extremely strong and certainty very high. Unfortunately, without an understanding of the nature of science and scientific inquiry, it is possible to be deceived or manipulated by a slim margin of uncertainty.

Of all the climate experts—individuals with the resources, knowledge, and experience to make informed analysis—97% support the consensus that humans are responsible for climate change.[20] Yet there continues to be significant doubt, largely among non-scientists, concerning the impact of humans on climate change. With the increasing role science, technology, and engineering play in personal and global well-being, it imperative that all citizens hold a functional understanding of the nature of the science and demonstrate a working knowledge of scientific literacy. The Next Generation Science Standards identifies the following basic understandings that all high school graduates should have about the nature of science for which the foundations need to be established in elementary school.[21]

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge Is Based on Empirical Evidence
- Scientific Knowledge Is Open to Revision in Light of New Evidence
- Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- Science Is a Way of Knowing
- Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science Is a Human Endeavor
- Science Addresses Questions About the Natural and Material World

The nature of science is not a separate NGSS dimension. The understandings of the nature of science are embedded in lessons and modeled by teachers. The nature of science is also reflected through lessons about the history of science. One of the most famous examples is spontaneous generation, the belief that life can emerge from nonliving matter. This idea was fueled by observations of rotting meat in which maggots seemed to spontaneously appear. As early as 1668 an Italian scientist named Francesco Redi thought otherwise, suggesting that maggots came from eggs laid by flies in the meat. He tested his hypothesis by boiling meat in several flasks, sealing some and leaving others open. Sure enough, maggots only grew in the open flasks exposed to air. However, most people were not convinced, suggesting the data only proved that spontaneous generation required air. It was not until 1859 when Louis Pasteur boiled meat in a flask in such a manner that air could enter the flask but not microorganisms that the refutation of spontaneous generation was accepted by the scientific community. While this example may seem remote, new evidence about health and medicine is constantly changing our lifestyles. Each day we are faced with reports about dieting, exercise, and drugs that claim to improve our lives. Should children be vaccinated? How much sunblock is necessary? Will cell phones cause cancer?

Science as a Set of Values

Although there are many values you can emphasize as you help children experience science processes and learn core ideas and crosscutting concepts, there are six that you will find particularly useful:

1. Truth
2. Freedom
3. Skepticism
4. Order
5. Originality
6. Communication

Because science seeks to make sense out of our natural world, it has as its most basic value the search for the truest, most accurate explanations based on evidence. A scientist seeks to discover not what should be but what is. The high value placed on truth applies not only to the discovery of facts, concepts, and principles but also to the recording and reporting of such knowledge.

The search for explanations relies on another important value: freedom. Real science can only occur when a scientist is able to operate in an environment that provides him or her with the freedom to follow paths wherever they lead. Fortunately, free societies rarely limit the work of scientists. Freedom to follow pathways also means the freedom to risk thinking independently and creatively. As educators, we must provide opportunities for students to think while taking care to think with, not for, students. Let me state that again: We must think *with*, not *for*, students. Thinking with students means modeling and guiding scientific thinking. Some of the best opportunities occur when we do not know the answer to a student's question, which will inevitably be the case no matter how much we prepare. This can be a time to panic and brush the student's question aside for fear of looking ignorant, or it can be a teaching and learning opportunity by which we model good thinking as lead learners. We can foster the development of foundational thinking strategies so that children take advantage of the freedom to think afforded them in our open society. A successful free society depends on the ability of its citizens to make informed decisions.

Skepticism—the unwillingness to accept many things at face value—moves scientists to ask difficult questions about the natural world, society, and even each other. Scientists value skepticism, and skepticism sometimes causes nonscientists to doubt the results of scientific enterprise. We will teach our students to be informed skeptics and teach them to argue scientifically so that their skepticism fosters constructive discussion that leads to deeper understanding.

There is, then, an underlying order to the processes and content of science. As suggested, science is a systematic process. There are many ways to study phenomena. The marine biologist observes dolphin behavior, while the botanist tests the effects of soil samples on plant growth, and the molecular biologist seeks ways to manipulate genes. All are collecting data in different ways. But all have a deliberate and organized plan for collecting and organizing data. It is this systematization and order that allow scientists to discover patterns in the natural world. Children need to develop this ability to organize information, which is why you will be helping them learn how to organize and keep track of their observations and discoveries.

For all its order, however, science also values originality. Although some may view science as a linear activity—one in which people plod along, acquiring more and more detailed explanations of phenomena—in reality, science is fueled by original ideas and creative thinking. It is this kind of thinking that leads to discoveries. Children have wonderful imaginations that can be assets for their science learning. As teachers, we can nurture and foster their imagination and creativity while learning science.

Children love to talk with each other; so do scientists. The talk of scientists includes reports, articles, speeches, and lectures, as well as casual conversations. The ability to communicate results and ideas is vital if knowledge is to grow. Without extensive communication, progress would be greatly limited. Students will learn how to argue scientifically and use claims, evidence, and reasoning to support their arguments and to critique those of others.

As a teacher, you will need to help children understand that science is more than a collection of facts and a group of processes. Science is a human activity that has as its framework a set of values that are important in day-to-day life.

Developing a Science Learner Identity Our goal as teachers is not to inspire all students to become scientists or engineers. Neither is it our goal to inspire students to become journalists, lawyers, plumbers, or carpenters. It is our goal to inspire students to believe in themselves as individuals with the ability to learn in any of these disciplines.

Developing Positive Affect For many teachers, a lesson about a caterpillar becoming a butterfly will only be about a caterpillar and a butterfly. But the same lesson in the hands of a master teacher—a great teacher, an extraordinary teacher, a truly gifted teacher—will be an experience in which the children are thunderstruck with the realization that one living thing has become a completely different living thing right before their eyes.

The day of that lesson will be one on which those children's lives will be changed forever. They will leave school filled with a sense of wonder that was sparked by the thrill of discovering brand-new knowledge that is as extraordinary as anything they will see on television. They will want to know more—curious about what may lie around the corner. They will also leave with new attitudes, values, and a confidence in their ability to learn that will shape who they are and who they will become.

This change in attitudes and values signals the development of positive affect. The science experiences you deliver to children will do much to create positive affect about science, school, and the wonders of the natural world. Most of all, we want our students to believe in themselves as successful learners of science, to "think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science."[22]

Developing Psychomotor Skills You might not think of your classroom as a place where children learn to coordinate what their minds will do with what their bodies perform—but it is. Children need to develop gross motor abilities as well as fine motor skills, and well-planned science experiences can help them do so.

Gross motor skills can be developed through inquiry-based activities such as assembling and using simple machines, hoeing and raking a class vegetable garden, and carefully shaping sand on a table to make various landforms. Examples of experiences that develop fine motor skills include cutting out leaf shapes with scissors, drawing charts and graphs, and sorting seeds on the basis of physical characteristics. So, in addition to gaining knowledge and understanding and developing positive affect, science time can be a time to improve a child's physical skills.

Developing Responsible and Informed Citizens When your children look at you during science time, they aren't thinking about issues such as raising taxes to pay for a park's underground sprinkler system or what impact the new factory under construction in town may have on worldwide CO_2 emissions and global warming trends. However, at some time in their lives, they will be called upon to make decisions that will significantly impact them as individuals, members of a local community, and part of a global community—decisions that no generation before them has had to face. And to be responsible citizens, they will need to address such issues with wisdom—wisdom and the ability to make informed decisions based on a foundation of knowledge and evidence.

With your guidance, children will learn that real inquiry requires gathering evidence before reaching a conclusion. Learning to gather knowledge systematically and to reach carefully thought-out conclusions will be skills they apply as they confront personal and societal issues in the future. If we do our job, then today's children will be prepared to make positive contributions to the civic decision-making processes that will lead to a better life for us all.

To create citizens who understand the implications of developments in science and technology is an enormous task. But the task for you, as a teacher, is more specific and reachable: teaching children to become scientifically literate. There is debate about what it means to be scientifically literate. Scientific literacy is less about *what* one knows as it is about *how* one knows. A scientifically literate person seeks to understand the reasoning behind claims. They do not have to agree with the claims, but they should be able to discern whether the claims were made based on evidence, how the evidence was collected, and who collected the evidence. Even the most experienced scientists have to rely on evidence and data analyzed by others to make informed decisions. All citizens should be familiar with questions to ask that support evidence and analysis:

> What is the question/problem? Who is collecting the data? What is driving them to collect the data? How did they collect the data? Was the data critiqued by other respected experts in the field? Being scientifically literate means knowing enough about the practices and core ideas of science to ask these types of questions and make informed decisions based on the answers. Scientific literacy is not just for scientists. It informs our big and small judgments spanning decisions about our health, government, and even the pair of shoes we buy. Does that belly band really take inches off your waist? Will krill oil improve liver, heart, and brain function? You can get both for the low price of $19.99! Scientific literacy helps us to make informed decisions by asking, "What's the evidence?" "How did

you get the evidence?" "How did you analyze the evidence?" "What does the evidence mean?" "What did other, non-biased experts in the scientific community have to say about it?" As an elementary teacher, you will start your students on the path to scientific literacy.

Equity Issues: Your Science Teaching Will Help Resolve Them

The scientist is a brain. He spends his days indoors, sitting in a laboratory, pouring things from one test tube into another. . . . He can only eat, breathe, and sleep science. . . . He has no social life, no other intellectual interests, no hobbies or relaxations. . . . He is always reading a book. He brings home creepy things.[23] Although students made these observations almost 50 years ago, their attitudes reflect, to a large degree, the views of society today. The students' choice of pronoun does not seem to reflect the purposeful use of *he* for *she* but rather the strength of the stereotype of the scientist as a white male.

Such stereotypes may discourage young females, minorities, and students with disabilities from considering science or science-related careers and foster the notion that they are not expected to succeed in science. Hopefully, you will be a classroom leader who is able to create an environment that helps to overcome these stereotypes.

The science classroom can also provide you with a wonderful opportunity to assist children from cultural minorities and for whom English is not their first language. When children are encouraged to explore phenomena that are real to them, to learn and use inquiry skills, and ultimately to make their own discoveries, the power of these experiences will do much to integrate all children into the task at hand.

Just think of how fortunate you are to teach children science, a subject whose natural allure for children will draw them into learning experiences irrespective of gender, language, and cultural barriers. By having a classroom that respects racial, gender, socioeconomic, and linguistic diversities, you can make a real difference in the lives of children. That's right! You can and will make a difference.

Your Attitude Makes a Difference

If, as a teacher, you emphasize only the facts of science, children will learn that science is an accumulation of factual knowledge. However, if you emphasize the process of science, children will learn that science is a way of seeking explanations. A well-rounded student understands science as both a process and a body of knowledge. Children will enter your classes with their own perceptions of science formed through experiences outside of school, at home, and through the media. As their teacher, you will have a significant impact on their understanding and attitude about what science is and how science is done. It is not only what you teach but also your attitude toward science that will impact students.

Consider Ms. Jones, a third-grade teacher, on bus duty early one spring morning, greeting and directing the children as they clamor off the buses. Ashley, a curious third-grader, can hardly contain her excitement as she runs up to Ms. Jones with a plastic container teeming with wriggling worms she and her mother found while planting a garden. Ashley grabs a handful of worms to show Ms. Jones and asks excitedly, "Can we keep them in the classroom?"

Ms. Jones smiles and shares in Ashley's excitement. "Wonderful idea Ashley," she exclaims. "Let's build a home for them. What do you think the worms will need in their home to stay healthy?" Ashley pauses and wonders, "Well, I found them in the garden. They probably need dirt." Ms. Jones, replies, "Great idea, Ashley. I wonder if any dirt is okay to use, and how much dirt should we get?" "Hmmn," says Ashley. "I don't know. What do worms eat?" "Great question," responds Ms. Jones. "Maybe we can share your discovery with the class, and present the question about a suitable home (habitat) for the worms and see if they have ideas about how to find out what the worms need."

Soon the class is planning an investigation by visiting gardens, searching for worms, testing the properties of the soil, and measuring the depth at which worms are found.

Connecting Technology and Engineering in Your Teaching

What do these terms have in common: video games, solar panels, prescription drugs, fuel cells, autonomous cars, CAT scans, X-ray treatment for cancer, and ramen noodles (noodlelike material that can be reconstituted through the addition of tap water)? The answer, of course, is technology. They all are products or procedures that apply science to the solution of human needs and desires—real or imagined.

Today, one of the most immediate challenges concerns climate change and the rising costs and finite supply of fossil fuels, which have created a need to seek alternative methods to generate energy. Green buildings that take advantage of wind, solar, geothermal, and even human energy are emerging at an increasingly rapid pace. These technologies integrate Earth science, energy transfer and conversion, simple machines, and biology in meaningful and relevant contexts. In your role as an elementary school teacher, you will have a tremendous opportunity to lay the foundation of energy literacy for generations of young people who may become engineers, architects, and designers who make pivotal decisions about lifestyle changes that will affect our planet and its inhabitants for years to come.

Changes in technology are occurring more rapidly than perhaps at any other time in history. The computers and smartphones we are using today will likely be outdated within the year. Drones, self-driving cars, and virtual reality are already realities, posed to play increasingly significant roles in our society. Biomedical engineers continually create new devices to speed recovery, treat emergencies, and restore movement, sight, and hearing. Technology, science, and engineering are integrally connected. Engineering is the application of science to serve human needs through design and development processes that lead to new technologies. Science, engineering, and technology are mutually beneficial. Needs and desires inspire engineers to apply scientific principles in creative ways. The technology that results often helps scientists investigate more deeply explanations of natural phenomena.

How might teaching about technological design be translated into your own real-world classroom?

Some building projects that are easily integrated into technology/engineering design projects are as follows:

1. A bridge out of newspaper and tape that supports two bricks and has a clearance of 12 inches
2. A machine for removing and sorting garbage and trash from lunch trays
3. A solar oven to cook s'mores
4. An automatic fish feeder for the aquarium during vacations

The point is that new and emerging technology impacts virtually every minute of a child's day. In order for children to lead lives in which technology is used intelligently, with minimal negative side effects, they need to understand how technology, engineering, and science are related, how new products and procedures are designed, what science is applied, what resources are needed, and what deleterious consequences may occur, such as allergic reactions, environmental pollution, and safety hazards. Students need to fully understand the larger impact of science, engineering, and new technologies within the context of how they affect their communities—and themselves.

REALITY Check

The NGSS provide many resources to guide your teaching. To become familiar with the three dimensions of the NGSS (science practices, disciplinary core ideas, and crosscutting concepts) imagine you are preparing a unit about forces and interactions for your third-grade students. Go to the NGSS website. Navigate through the site to find a standard 3-PS2-1. Identify the performance expectation that your students should be able to demonstrate by the end of third grade along with the science practices, disciplinary core ideas, and crosscutting concepts associated with the standard that will inform your unit. How does the standard relate to the nature of science and the Common Core State Standards?

Yes, You Can Do It! Science for All Children, Every Day, in Every Way

This text is full of resources that will help you create wonderful classroom experiences for children—experiences in which they explore, inquire, and discover. In Part One of this text (which includes this and the next five chapters), you will learn basic science-teaching methods that will help you create that wonderful classroom! And beyond Part One, you will find three very specific parts of the text that deal with teaching the Earth/space sciences, the life sciences, and the physical sciences. In the Appendix, you will find unit and lesson "starter ideas," activities and demonstrations as you prepare to teach children science.

I am confident that you will be successful if you are motivated to use your talent to its fullest and the available resources to the maximum. If you do, each day in your classroom will be a day when every child has the opportunity to explore, inquire, and discover. So get started on your journey to discover how children actually learn science.

Summary

1.1 Develop a working definition of science.

Science is both a body of knowledge about the natural world and a systematic way of gathering knowledge. Scientific thinking can be thought of as a progression of inquiry consisting of descriptive, explanatory, and verification models. Scientific ways of knowing do not consist of one sequential set of tasks. On the contrary, seeking explanations based on evidence uses many approaches ranging in degrees from experimental to field based, all of which represent systematic, well-thought-out approaches.

1.2 Describe how research about learning science informs science teaching.

The following principles are from *How Students Learn: History, Mathematics, and Science in the Classroom* (Bransford & Donovan, 2005):

- Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom. Building on and challenging students' prior knowledge will allow students to adapt and modify their understanding and make learning both relevant and meaningful.
- To develop competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application. As science teachers, we can assist students in making connections of facts to concepts that help students make sense of the world. Teaching both facts and the concepts in a meaningful context will help students make sense of new knowledge and organize it in a way that supports retention.

- A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.
- Metacognition is a term that will not be familiar to our students, but one that we need to think about and inform our teaching. Metacognition in the context of teaching and learning is self-monitoring of one's learning. It could be rehearsing a phone number to remember it, or asking probing questions about a new idea to figure out what it means and how it fits with preexisting ideas. I often think of good detectives, who ask probing questions that follow up previous responses, as an example of challenging ideas and monitoring one's learning to get to the bottom of a case. Scientific argumentation is similar and a strategy you can promote in the science classroom.
- Learning science requires students to be participants in doing science.

  Doing science means dealing with the uncertainty of not knowing the answer and using a variety of thoughtful systematic strategies to seek an explanation. It requires imagination and creativity, looking at events and phenomena and thinking about explanations and solutions in novel ways. When we teach students science, we guide them to use observation, reasoning, creativity, and imagination to think in ways that are new for them and lead them to personal discoveries and deeper understanding so they can make sense of the world.

1.3 Describe the purpose and three dimensions of the Next Generation Science Standards.

The Next Generation Science Standards were developed by teams of scientists and educators to identify what students in each grade should know and be able to do with respect to science and engineering. They consist of three dimensions: science practices, disciplinary core ideas, and crosscutting concepts. Three dimensional instruction means using each dimension together, not in isolation, to help students make sense of phenomena or figure out solutions.

GOING FURTHER

On Your Own or in a Cooperative Learning Group

1. Think about your experience in science classes. What did you enjoy? What didn't you enjoy? More importantly, how were you engaged and inspired to learn science? If you were not engaged, what disengaged you? How would you want students to describe the science learning experiences that you lead?
2. If possible, interview an elementary school teacher to find out how she or he answers such questions as these: What does science mean to you? What do your students thin k science is? What advice can you provide about how children learn science?
3. Ask friends, family, colleagues what they think science is and what the nature of science means to them. Ask them their ideas about how children should learn science.
4. Talk with your colleagues about how gender, race, ethnicity, and culture, your own and those of your students, could inform your science teaching.
5. A criticism of science education has been that we teach students *about* science rather than having them *do* science. Interview a scientist and a non-scientist about what it means to *do* science. Write an article or produce a brief video about what you discover.
6. Do you consider yourself scientifically literate? Why or why not?

RESOURCES FOR DISCOVERY LEARNING

Internet Resources

- **Next Generation Science Standards:** www.nextgenscience.org
- **Common Core State Standards:** www.corestandards.org/
- **National Science Teachers Association:** www.nsta.org
- **Phenomena** https://www.nextgenscience.org/resources/phenomena
- **Skeptical Science:** https://www.skepticalscience.com/

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CHAPTER 2

Science Practices and Inquiry Process Skills

How can I help children use science and engineering practices to make discoveries?

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Learning Objectives

After completing the activities in this chapter, you should be able to:

2.1 Create a vision for discovery learning in your classroom.

2.2 Describe science practices and inquiry skills as they relate to learning science and engineering.

▶ GETTING STARTED

Her lips are starting to swell and crack under the broiling desert sun. Hot dry air has been relentlessly attacking since daybreak. She stops for a moment, lifts the bandana covering her mouth and nose, and shakes out her stringy hair. Incredibly, with that headshake, something catches her attention. To her left, a tiny, gray fossil bone fragment sticks out from the soil. The last gust of wind must have revealed it. Now she doesn't feel the sun or the heat or the dust at all! Her full attention is focused on the fragment.

A series of images flashes through her mind as she compares what she can tell about this fragment to what she already knows. Her mental pictures are of dinosaur skeletons, and none has the anatomical structure into which this tiny bone would fit. It is a toe bone, for sure—but one she has never seen before. Her heart starts to race at the thought of this.

From her grimy tool pack, she carefully pulls several tiny dental picks and small brushes and gently works away the material around the bone. With each gentle poke and sweep of the brush, she grasps more clearly what has just been revealed to her eyes alone: A brand-new dinosaur has stuck its toe into her world and ours. Her careful observation has led to an extraordinary discovery.

She will draw the fossil, photograph it, plot its location, and then ever so slowly search the surrounding area for mor e fragments. Eventually, she will pull from the reluctant Earth a creature that so far has only been imagined. A wonderful discovery has been made—and she made it!

A Vision For Learning Science and Engineering through Discovery

Discovery learning has its foundation in constructivist learning theory, which is based on the premise that learning builds upon past experiences and new interactions with ideas and phenomena through exploration and manipulation.[1] In his book *The Act of Discovery*, Jerome Bruner advocates for a discovery learning.[2] When we discover, we find or gain knowledge, usually for the first time, using our own mind. In doing so, we as learners have invested in the acquisition of knowledge, and the knowledge takes on relevance and meaning. Bruner states that "the most uniquely personal of all that he (humankind)[3] knows is that which he has discovered for himself."[4]

In terms of learning, discovery for students is *making sense of the world* based on accurate scientific concepts and principles. This is a key point. While discoveries by your students will likely not be new to the scientific community, they will be new to your students. The idea behind *discovery* as it is used in this text is that students will actually engage in the practice of doing science rather than learning about science secondhand, resulting in a deeper understanding of scientific practices and content. Keep in mind that learning is an iterative process. Deeper understanding is built slowly over time. Resist the temptation to teach everything there is to know about a topic in one lesson. Knowing what *not to* teach is as important as knowing what *to* teach. Students' understandings will progress throughout their formal and informal education as lifelong learners. You, as the elementary science teacher, have a unique opportunity to establish a foundation upon which your young students will learn to think like scientists and engineers. Therefore, the practices and skills introduced in this chapter are among the most important you can initiate among your students to start them on a path of critical, evidence-based thinking that is the foundation of scientific and engineering ways of knowing.

When we teach with the focus on discovery, we prepare children to make personal discoveries with our guidance. We equip them with their very own "tool packs." And with any luck at all, they will use those tools in a variety of contexts throughout their lives. It is possible that a few children may find brand-new dinosaurs, but more importantly, all of them will use the tools of scientific inquiry to unearth evidence and develop the concepts, principles, attitudes, and values that will help them lead full and productive lives.

Discovery suggests that we need to respect and value learners and their role in constructing knowledge. As teachers, we cannot learn for our students; each child ultimately needs to forge his or her own understanding. Problem-based learning, project-based learning, expeditionary learning, and case-based learning are some of the many expressions of learning that are discovery based.

How Do I Teach So Discovery Learning Happens?

In the words of Louis Pasteur, "Chance favors the prepared mind." The same sentiment is shared by Jerome Bruner when he states, "Discovery, like surprise, favors the well-prepared mind."[5] By teaching science, you are preparing young people's minds to make discoveries. Discovery learning happens when a child uncovers new information, makes new connections, and gleans new insight that deepens his or her understanding. It is an individual and personal experience. Children need to discover new knowledge that is meaningful and offers a better explanation than their prior understanding. Otherwise, common misconceptions can persist into adulthood. A classic example is the reason for the seasons. Most people are taught the reason for the seasons at some time in their schooling. Yet, when asked to explain the reason for the seasons, their explanation falls short or is incorrect.

To teach for discovery learning, you must, wherever possible, provide hands-on, mind-stretching experiences that will enable children to use their knowledge and skills to make discoveries. Your challenge is to provide physical and intellectual contexts that inspire new discoveries connected to past and to future learning.

Your role as teacher goes beyond providing students with the opportunity to discover; you must also teach them how to discover. Your charge is to craft interactive learning experiences that guide students to develop the intellectual and physical tools necessary to seek explanations.

Discovery Is a Time of Enthusiasm, Excitement, and Energy!

Many of the preservice elementary teachers in my classes worry about the apparent lack of structure associated with a classroom of third-graders actively engaged in "doing" science. Discovery learning is filled with excitement. Not unlike a three-ring circus, there can be a lot of activity during discovery. Some students will be talking to each other, others will become animated; they will argue, wonder, and test ideas. This is good. If they are wondering and arguing about the science and/or engineering challenges you provide, congratulations, you are doing our job well. The science classroom should be dynamic and filled with energy. But there will be quiet, reflective times as well. The discovery process has a rhythm of learning alternating among periods of high activity, individual reflection, peer discussion, and explanation. Okay, it's true: Some science classrooms do become a bit chaotic, which can be unnerving. This is often a concern, especially for new teachers who are just developing their classroom-management strategies. It happens from time to time when teachers make the naive assumption that if they just provide a super-rich context of science "stuff," then good things will automatically happen. Well, sometimes they do, but they usually don't.

A science teacher must carefully plan student encounters with new ideas and orchestrate learning experiences that appear spontaneous to the casual observer but are nevertheless well planned and executed. There is nothing accidental about good teaching. Teaching discovery does not happen by simply providing an engaging activity and hoping children will learn something of value. Avoid the temptation to let the activity drive the learning. Watching the product of baking soda and vinegar bubble out of a volcano may be engaging, but it can also be misleading with respect to the true mechanism of volcanic reactions. Select activities carefully and use them as experiences to develop the targeted learning objectives.

The term *inquiry* has been used extensively in science education, particularly in science education reforms of the recent past. As a result, the term *inquiry* has been interpreted in several different ways. Therefore, the Next Generation Science Standards associate science practices with science inquiry to better specify what is meant by inquiry. In this chapter, we take a closer look at inquiry and the science practices.

What Is Inquiry?

I will explain inquiry as clearly as I can, beginning with this straightforward definition: Inquiry is the careful and systematic method of asking questions and seeking explanations.

As suggested in Chapter 1, systematic does not suggest a single method or approach. The idea of a single scientific method is inaccurate and an oversimplification. Distance yourself from this idea. It is better to think of science and engineering methods as carefully planned investigations to collect valid and informative evidence to explain phenomena, answer questions, solve problems, or design solutions. Evidence consists of measurable data and can be either qualitative, quantitative, or both. Evidence is used to support or fail to support proposed explanations.

When students are actively involved in the processes of inquiry, they learn to inquire and employ science practices, concepts, and skills to seek explanations and make better sense of their worlds.

Learning Content Through Inquiry and Learning to Inquire

Learning content *through* inquiry means that the students construct knowledge through the processes of asking questions, seeking evidence, formulating explanations based on evidence, and justifying their explanations. Learning *to inquire* means students become aware of and consciously apply the processes associated with inquiry as part of their thinking strategies. Learning through inquiry and learning to inquire are complementary and often taught simultaneously.

The use of inquiry to learn science practices and core concepts varies on a continuum of teacher and student participation in the inquiry process. Inquiry is considered more guided to the degree that the teacher makes decisions about the inquiry processes for students and more open if students make decisions about inquiry on their own. The student who asks a question or makes a claim, seeks evidence, and formulates and justifies an evidence-based explanation on his or her own is participating in open-ended inquiry.

The NGSS Science and Engineering Practices

This section addresses the NGSS science and engineering practices. Later in this chapter we will address inquiry skills. Practices are distinguished from skills in that practices are accompanied by knowledge and understanding about how skills can be used to make sense of the world. Skills could be thought of as techniques that one could practice without knowledge of their application or purpose. Most of the practices in science and engineering are similar enough to be addressed together. We will consider them separately when necessary.

Asking Questions and Defining Problems Knowing the best questions to ask is the first step in seeking an explanation. Science usually begins by asking questions about phenomena—for example, "Why does my dog walk in circles before it lays down?" or "How do turtles find their way back to their birthplace?" Engineers usually begin with a problem that needs to be solved—for example, "Plastics don't decompose easily and pose a danger to marine life. How can we make plastics more environmentally friendly?"

What kinds of questions should you encourage in your elementary students? Good science and engineering questions can be answered using evidence collected from direct observations or secondary data (data collected by someone else and accessed by the user). Questions such as "How do people catch colds?" or "How do hurricanes form?" can be investigated based on data collected by students or data shared by others. Questions based on values or opinion generally are not good scientific questions—for example, "Is football a better sport than hockey?"

In a later chapter, we will address strategies for questioning students. Here the focus is on the types of questions that we want to encourage students to ask. Children's questions frequently fit into one of the following categories:

- **Information-seeking questions:** Often students seek information to better understand a system. They need more facts: "Do frogs have teeth?" "What does a snake eat?" These are convergent questions, and the information can be acquired through direct observation or from a secondary source. Information-seeking questions provide opportunities for students to develop basic observational and descriptive skills. Don't dismiss these questions. If students ask whether frogs have teeth, make a claim based on their prior knowledge, and seek confirmation by looking in a frog's mouth, they are practicing scientific ways of thinking!
- **Wonderment questions:** Students may ask, "I wonder what will happen if . . . ?" These questions suggest a proposed relationship between two variables. Such a question is a precursor to an investigation. For example, a student might say, "I wonder what would happen if I used two batteries instead of one in the circuit." The student might predict that the light will get brighter. If she tests her prediction by adding a second battery to the circuit, records the data, and uses the data to confirm or falsify her prediction, she is doing science.
- **"How does it work?" questions:** How something works can lead to rich scientific reasoning. *How* questions seek explanations. Such questions include science-centered questions such as "How do penguins survive the cold?" and engineering-oriented questions such as "How does a solar panel work?" These higher-order questions may be phrased in more than one manner, sometimes beginning with *what* or *why*: "What causes the seasons?" "Why do cats have whiskers?" These types of questions present real opportunities for inquiry—if the teacher takes advantage of the question. Instead of telling students the answer (transmissional teaching), guide students to employ science practices and use inquiry skills to seek their own explanations. Encourage them to observe more closely, ask questions

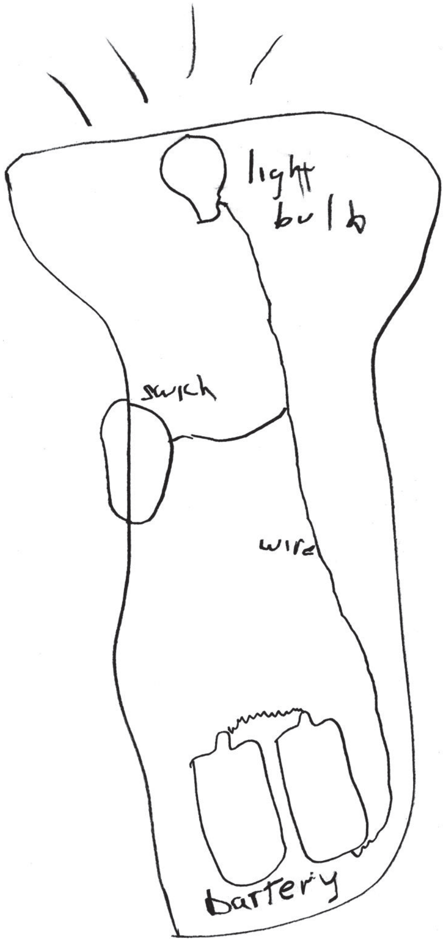
based on observations, look for evidence, generate ideas, test ideas, and share results. For example, observe cats, note how they use their whiskers and the structure of whiskers. Generate specific questions about whiskers, test ideas by observing other animals with or without whiskers, and share ideas with classmates, teachers, and if possible, experts.

- **How-to-solve-a-problem questions:** How to solve a problem is at the heart of engineering. It often leads to modification of an existing system or the creation of a new one. Students might ask how to make an automatic feeder for the class gerbil or how to make a birdfeeder that is squirrel-proof. Your job is to guide the design process so that students become aware of the iterative design, build, test, analyze, and redesign processes of engineering.

There are many other ways to categorize questions: convergent and divergent; descriptive, relational, and causal. I find the categories described above easy to identify and work with at the elementary level.

Developing and Using Models Scientific models are representations of systems or phenomena that can help explain and make predictions regarding phenomena.[6] They can be diagrams, three-dimensional models, computer simulations, mathematical representations, or analogies. Models can be mental representations as well. Most important is to recognize that models are more than descriptions or miniatures of a larger object, such as a model house or model car. Art projects, while important in their own right, are not scientific models if they are not useful for explaining or predicting. Models have explanatory power that moves beyond description or definition of a concept.

Figure 2.1 Observation is the most basic of all inquiry process skills.



The big idea for the use of models in science education is that students should develop models to represent their understanding and revise their models through an iterative process based on new evidence. For example, at the beginning of a unit on electricity, fourth-graders were asked to diagram their model of the inside of a flashlight and to use the model to explain how the flashlight (a simple circuit) works. An example of a student diagram is provided in Figure 2.1.

As units progress and students acquire more evidence about circuits, their understanding is reflected in revised models that not only support explanation and prediction, but also provide important formative assessment.

Modeling in particular invites students to observe, create, and analyze representations of phenomena. Modeling affords particularly rich language demand opportunities for all students, but can be especially supportive for English language learners (ELL). Diagrams, illustrations, three-dimensional models, and virtual representations are largely language independent and allow students to express their sense-making with minimal reliance on language. Students may not know the term for a lever or how to describe the relationships in a food web, but they can point to these ideas in a diagram or picture to express their thoughts and understanding. Furthermore, the desire to share descriptions and ideas motivates students to develop language skills. Using a model to clarify an explanation of simple circuits in a flashlight can support and enrich students' language use for explanations and predictions of simple circuits.

Planning and Carrying Out Investigations Planning and carrying out investigations may seem like a tall order for elementary school students. I know graduate students who struggle with such challenges. As elementary teachers, you are called to set the foundation for children to plan and execute scientifically sound investigations. It takes time, just as developing other knowledge and skills. The important help you must provide is to start them on the journey of developing science and engineering knowledge and skills. In elementary school, the NGSS suggest that K–2 students build on prior knowledge from and progress to simple investigations based on fair tests, which provide data to support explanations or design solutions. In grades 3 through 5, students carry out investigations with controlled variables and provide evidence to support explanations or design solutions.[7] This is a good time to distinguish between data and evidence to clarify the progression from K–2 to 3–5 students. Data and evidence are often used interchangeably, but they are distinct. Data are factual pieces of information that often consist of raw measurements. Data may or may not be relevant for an explanation. Data become evidence when they are used to justify an explanation. For instance, increased average global temperatures and increased levels of atmospheric CO_2 are data. Together they can provide evidence of global warming caused by increasing levels of CO_2. Does this still seem overwhelming? It need not be.

I use termites as a phenomenon to introduce students to the idea of planning and carrying out investigations. Termites will follow fresh lines made with ink from certain pens.

The ink contains a chemical closely related to a tracking pheromone that the termites use. The chemical is present in some but not all inks. The students observe the termite behavior and immediately question how the termites follow the ink trail. With very little or no prompting, they begin to propose explanations. Common explanations suggest that the termites follow color, texture, shape, or type of ink. Third- and fourth-graders spontaneously begin to draw different shapes or use different colors with different pens in an attempt to see what the termites will do. They are collecting data. Most of these forays are ill planned, having no controls or identification of independent or dependent variables. It is at this point that I stop the class (not an easy feat, given the children's excitement) to identify students' questions, ideas, claims, and evidence. Together we plan a fair investigation by controlling variables, manipulating just the independent variable, and deciding the type of data we will collect to measure the dependent variable. Students can now carry out the investigation using different-colored pens, textures, shapes, or types of ink in a systematic manner. They collect more data and use it to explain the termite behavior—that is, termites are attracted to the type of ink used.

Engineering design emerges easily by challenging students to design a way to use their discovery to create a way to control termite infestations. You would be surprised with the creative and innovative ideas students generate—for example, use the ink to lure termites away from buildings.

A final note about planning and carrying out investigations is to help students recognize that the natural world is often the setting for investigations. Did you ever wonder when the leaves on the old oak tree will appear (referred to as budburst)? A look at the past data in your region will reveal that the time of budburst has varied over the years.[8] You might challenge your students to predict when the buds will burst. To find out, have students adopt a tree in the schoolyard. Each day they collect data (e.g., temperature, rainfall, day length [9] and make qualitative and quantitative observations of the buds: color, size, shape. Have them keep a record of these variables accompanied by occasional drawings or photographs of the buds. Soon the students will realize that they need a definition of budburst. How will they know it when they see it? They do some online searches and find out that the scientific community identifies budburst at the time when new leaves are visible through openings in the swollen bud. Finally, the day arrives and they confirm budburst by having three independent classes observe the buds. Next they look for patterns in their data that might explain the signs leading to budburst. Students use the data as evidence to make claims, and then share their evidence and reasoning with classmates.

Analyzing and Interpreting Data At the elementary level, students begin to arrange their data to display patterns. You can scaffold the presentation of data by creating tables, graphs, diagrams, or similar ways to display data. Be creative. Square-foot floor tiles work wonderfully for making large bar graphs. When I plan a discovery unit that investigates plant growth, I have students arrange their data such that it displays a pattern that they can recognize. Note how the data are organized in Table 2.1 to help the children see patterns.

Using Mathematics and Computational Thinking There is no getting around it: Mathematics is an elegant language for representing relationships in a concise and predictable manner. However, math has been known to turn people away from science and engineering. The math you teach to your elementary children need not be intimidating. Applications of math in science and engineering can be as simple as counting the number of acorns on the ground in a given area to study resources in an ecosystem. Technology provides easy methods for collecting data such as temperature or speed to generate data sets that young children can analyze. Simple bar graphs, scatter plots, and line graphs make relationships and trends easily recognizable. I challenge students to make pizza box solar ovens that heat up quickly and cool down slowly. Measuring temperature over time and graphing the data provide rate measurements. The slopes of the graphs clearly represent trends about the efficacy of their designs and provide feedback for redesign. Your responsibility is to think creatively about how you can integrate math and computational thinking into your science and engineering instruction.

Table 2.1 Comparison of plant growth

Day	Plant growth in inches with 4 hrs. of light per day	Plant growth in inches with 8 hrs. of light per day
1	0	0
4	2	4
8	3	6
12	4	7
16	5	10
20	7	14

REALITY Check

Make line graphs and bar graphs for the data in Table 2.1. Discuss the pros and cons of each with your colleagues. Integrate technology by using a program such as Microsoft Excel to make the graphs.

Constructing Explanations (Science) and Designing Solutions (Engineering) When all is said and done, constructing explanations based on evidence is at the core of science education. If students ask good scientific questions, plan and carry out investigations, collect and analyze data, then the culmination of their efforts should be explanations based on evidence. While they may not have a complete explanation or fully accurate understanding of the targeted concepts, they will have extended their knowledge and understanding.

When teaching students to construct explanations or design solutions, it is important that the learners express their own explanation or solution in order to effect conceptual change. Only after learners have expressed their discoveries should teachers challenge and guide their explanations. Communicating understanding is consistent with reflection that inspires ownership of learning through discovery. This approach will be addressed in more depth in Chapters 3 and 4.

Constructing an explanation means identifying the salient parts of a system, the properties and relationships among the parts, and how they all come together to make the system work. At first glance this may seem too advanced for elementary school children. For example, suppose a unit began with the essential question, "How are seeds formed?" To investigate, students grow and observe Fast Plants® over a period of about 35 days. At the end of that period, they have encountered the parts of the plant as it grows and differentiates, examined and described distinctive properties of the flower parts (stamen, anther, pistil), seen the flowers bloom, gathered pollen with bee abdomens, transferred the pollen to the pistils and noted the relationships among bees and plant parts, and observed the pistils swell and produce seeds. During this time the students will have kept notebooks and responded to guided questions and prompts. Having gathered data, they use the data as evidence to propose explanations. Lastly, students engage in discourse to discuss and critique explanations. The science circle is an example of a strategy to engage children in discourse. You will learn more about the science circle in Chapter 4.

Designing Solutions For engineering, the goal is to design and create solutions to problems. Making a bridge out of a limited amount of paper and masking tape that is 1 foot tall, spans 1 foot, and supports a stack of books (about 6 pounds) is a popular lesson. Sometimes I provide a budget for students and have them pay for tape and paper, thereby modeling economic limitations. As with all engineering endeavors, this turns out to be an iterative process during which the children plan, build, test, and redesign. Of course, there is a synergy between science and engineering that leads to great complementarity in the classroom. Building bridges leads to considerations of energy and forces.[10] Reading, writing, and communicating science explanations and design solutions creates a need for students to use language in context or to meaningfully employ "language for use."[11]

Engaging in Argument from Evidence Talking about an idea forces one to think about it. Being challenged to defend an idea makes one think about it deeply and sometimes passionately. Good arguments are rich learning experiences. Sometimes I find it unfortunate that we use the term *argument* to refer to specific science discourse. Colloquially, *argue* has a negative and combative connotation. *Argument* in the context of science is not a shouting match; it is a team effort to strengthen and improve an explanation through challenges from peers working to explain the same phenomenon. It is noble to revise or reject an explanation in light of good evidence. An argument in science is not lost if our understanding deepens.

Teaching children to make claims, gather data, use data as evidence to support claims, and explain their reasoning will engage and guide them in constructing arguments from evidence.[12] Doing so immerses students in discourse that requires them not only to use written and verbal language that clearly communicates their thinking, but also to read and listen to other children's claims, evaluate them, and challenge each other's arguments, thereby providing them with multiple ways of expressing ideas.

For example, I ask students to make a claim about whether a can of Diet Coke and a can of regular Coke will sink or float. Testing reveals that the Diet Coke floats and the regular Coke sinks. The challenge is to explain why. During investigation, students gather data and use evidence to make claims. They then justify and defend their explanations to their peers.

Developing explanations and designing solutions inspires language development by increasing the demand for clarity and precision. Both native speakers and ELL students will be challenged to communicate new thoughts and ideas about science and engineering using terms and ideas that are new to them, providing opportunities for scaffolding and support to nurture language development. Language demand is familiar to anyone who has traveled as a foreign speaker in a country. Necessity to communicate clearly and accurately creates a need to find the proper words and phrases to express our thoughts.

Obtaining, Evaluating, and Communicating Information Reading, writing, and verbally communicating ideas are not unique to science and engineering. One might argue that they are more appropriately addressed in language arts classes. Well, this may be true to some extent, but reading, writing, and talking about *science and engineering* are different than reading, writing, and talking about a novel, comic book, or newspaper. As suggested, science and engineering use precise language. Reading science and engineering requires attention to the specific meanings of words. Often terms are unfamiliar or understood differently outside science and engineering.

Obtaining information provides another point of reference for language learning. Students obtain information about science and engineering in a variety of ways through direct observation, textbooks, science stories in trade books, Internet websites, and popular articles about science. Science notebooks provide students with an opportunity to write about their observations. Technology allows for students to share their observations through video, audio, and various social media.

Young children need to be involved in describing their observations, investigations, results, and conclusions, beginning with their first science and engineering experiences.

To make a point for the importance of clarity when communicating ideas in science and engineering, a common activity is to make a jelly sandwich. (In the past, we typically made a peanut butter and jelly sandwich, but the prevalence of peanut allergies should give you pause before using peanut butter.) Be sure to precisely follow the directions given by the students. If you follow their instructions literally, they will soon realize that the outcomes are not what they intend. Another activity is to pair the students and provide one student with an illustration of different-colored shapes. Give the other student cutouts of the colored shapes. Have the students sit back-to-back. The student with the illustration must communicate the arrangement of shapes verbally, without either student looking at the other's shapes. Do this on a regular basis but change the shapes and patterns to coincide with the concepts you are teaching (i.e., wires, batteries, and bulbs for circuits).

Inquiry Skills

Recall that science is about the process of seeking explanations based on evidence. There are certain skills, frequently called *inquiry skills*, that children can develop to become better investigators.

Inquiry Process Skills Used to Create Descriptive Models

We begin with the inquiry skills commonly associated with descriptive models:

- Observing
- Using space/time relationships
- Using numbers
- Questioning
- Classifying
- Measuring
- Communicating

Observing I find that while teachers often ask students to make observations, rarely do we teach children how to observe. Observing means using the senses to obtain information, or data, about objects and events. Merely looking is not the same as observing. When we look at things, we are passive and wait for something to happen; when we observe, we are active participants. Casual observations spark almost every inquiry we make about our environment. Organized observations form the basis for more structured investigations. Acquiring the ability to make careful observations creates a foundation for making inferences or hypotheses that can be tested by further investigations and observations.

Sherlock Holmes continues to be a popular character in contemporary media, known for his powers of observation and clever inferences. Arthur Conan Doyle based the Holmes character on a real person, Joseph Bell, who was a Scottish surgeon during the late 19th and early 20th centuries. Are such powers of observation innate, or can they be learned? I think we all have potential to be like Sherlock Holmes. In fact, we routinely make observations, but we may not be aware of how we do so.

For example, imagine that you are assembling a jigsaw puzzle. You have a vision of the big picture given to you on the box, but you don't know how the 1,000 pieces in a pile fit together to make that picture. The first step is to identify the pieces by their properties: color, shape, and size. You might find the border pieces first because they help to define the boundaries of the puzzle. Next you look for possible relationships among the pieces. How do they fit together based on shape and color? While you do this, you continue to find new properties. Some relationships are easier to identify than others. Eventually the picture begins to fill in, and you see the final picture. The picture emerges from the unique pieces, their properties, and relationships. Peter Bergethon identifies five key questions that enable inquirers to be active observers. The parallel between these fundamental questions for observation and the puzzle example are listed in Table 2.2.[13] These

Table 2.2 Generalization of the fundamental questions for observation

Puzzle Terms	Questions for Observation
What are the pieces of the puzzle?	What are the parts of the system?
What are the properties of the pieces?	What are the properties of the parts?
What are the boundaries of the puzzle?	What is the context or background space of the system?
How do the pieces relate to each other?	What are the relationships (connections) among the parts?
What picture emerges when the pieces are put together?	What are the emergent properties (characteristics) of the system?

REALITY Check

Sample Activity: Developing Observation Strategies

To build habits of mind associated with descriptive modeling, begin each class with "Do Now" activity (a brief activity at the beginning of class that sets the tone for the class). Project pictures of familiar scenes for 1 minute and then take the pictures away. Ask students to describe what they observed. Review the descriptions in terms of the fundamental questions for observation. Project the picture again for students to see how accurately they observed. After a few classes, students expect to find a picture and immediately make their observations. As the weeks progress, exchange the familiar pictures with unfamiliar pictures and dynamic systems (microscopic images, pond life, ecosystems, molecules), and ask students to develop descriptions based on their observations. Doing so consistently over a period of time develops habits of mind associated with observation strategies for creating descriptive models as a first step to inquiry.

In addition to observing a static picture, have children use the fundamental questions for observation to describe an event or phenomenon. You might start by asking children to observe how a fish swims or a bird flies. Let the children watch real fish and birds. Show them a video of the same in slow motion. Ask them to make observations based on the fundamental questions to describe how the bird flies or the fish swims.

questions can guide our observations. It is a way to help us systematize the way we observe. The next time you are stuck on a problem, step back and ask yourself these five questions to see if you recognize any connections that may help you understand the situation better and make some connections and inferences of your own.

Using Space/Time Relationships All objects occupy a place in space. The inquiry skill using space/time relationships involves the ability to discern and describe directions, spatial arrangements, motion and speed, symmetry, and rate of change.

Sample Activity Many schools have square-foot tiles on the floor. Use the tiles to make a grid with an x and y axis. Roll a ball along the grid and show students how to describe the direction, speed, and even rate of change based on the path of the ball along the grid.

Using Numbers We need numbers to manipulate measurements, order objects, and classify objects. The amount of time spent on the activities devoted to using numbers is not relegated to the school's mathematics program. Using numbers is of course central for using mathematics and computational thinking.

PRACTICAL applications

Using Inquiry Process Skills to Create a Descriptive Model of a Butterfly

Table 2.3 illustrates how the fundamental questions for observation may be used to generate a simple descriptive model of a butterfly. Note how the descriptive model facilitates other inquiry process skills, such as enumeration (number of legs) and ordination (wings attached to the middle of the butterfly). Construction of a descriptive model inevitably leads to more system-specific questions: "Why do some butterflies have brightly colored wings while others have very plainly colored wings?" "How do butterflies eat?" and so on. Children can measure the length of the butterfly or the height and width of the wings. Children may use space/time relationships, noting that the butterflies move among similar types of flowers and are most active at certain times of day. Finally, children need to communicate their models, which can be achieved through a variety of modalities such as writing, drawing, verbalizing, or simulating. Note the dependency of a good descriptive model on the implementation of inquiry process skills.

Table 2.3 Description of a butterfly—based on the fundamental questions of inquiry

Parts	Properties	Background space	Relationships	Emergent properties
• Legs	• 5 (visible), black	• (while not apparent in the photo, the system takes place at a certain temperature, humidity, and light intensity.)	• Legs and wings attached to the middle of butterfly	• Colorful
• Antennae	• 2 Thin black		• Butterfly stands on leaf	
• Head	• Round, black			
• Wings	• Black with 14 white, 15 yellow, and 6 blue spots			
• Abdomen	• Black, white dots			

Sample Activity Encourage children to include quantitative observations in their descriptions. Growing plants can serve many learning outcomes. Look for opportunities to include numbers to support quantitative data collection: the number of days to germination, sprouting, blossoming, and seed production. Measure the number of plants, leaves, blossoms, fruits; height of stems, length and width of leaves. These numbers can be used to generate tables, charts, and graphs that will aid in pattern recognition and analysis. Nurture quantitative observations throughout your lessons to set the foundation for using mathematical and computational skills.

Classifying Classifying is the process scientists use to impose order on collections of objects or events. Classification schemes are used in science and other disciplines to identify objects or events and to show similarities, differences, patterns, and interrelationships.

Sample Activity Obtain a collection of plastic dinosaurs. Pictures will suffice if plastic representations are not readily handy. Tell students you would like arrange the dinosaurs for a display for family night, but that you cannot decide how to group them. Assign student groups to develop a grouping system (claim) and to explain their rationale for the groupings (reasoning based on evidence).

Measuring Measuring is of course an extension of using numbers. Skill in measuring requires the ability to use measuring instruments properly to collect precise and accurate data. The process involves judgment about which instrument to use and how to approximate measurements to ensure that the actual measurements make sense and are not blindly accepted. Children can learn to measure length, area, volume, mass, temperature, force, and speed as they develop this process skill.

Sample Activity Have children estimate the linear dimensions of classroom objects using centimeters, decimeters, or meters, and then use metersticks to measure the objects. Measure daily weather properties: temperature, rainfall, cloud cover, relative humidity, etc. Join students around the world using simple measurement protocols that provide scientists with valuable information. See the link at the end of the chapter to Global Learning Observations to Benefit the Environment (GLOBE) for vetted protocol data collection and sharing.

Communicating Clear, precise communication is essential to all human endeavors and fundamental to all scientific work, which makes communicating skills valuable. Scientists communicate orally, with written words, and through the use of diagrams, maps, graphs, mathematical equations, and other visual demonstrations.

Sample Activity Have each student make a map to a location of their choice in the schoolyard. You can set boundaries for safety. Have the children exchange maps and see whether they can find the location specified. Facilitate oral communication and language demand by simulating a launch to an international space station. Students must role-play specific responsibilities in mission control.

Inquiry Process Skills Used to Create Explanations

Explanations often begin with preliminary ideas based on observations generated using the following process skills:

- Inferring
- Hypothesizing and predicting

Inferring *Inferring* is using logic to make assumptions from data collected. The ability to distinguish between an observation and an inference is fundamental to clear thinking. An observation is based on an experience that is obtained through the senses. An inference is an assumption based on an observation. Consider the observation that butterflies are often found on flowering plants. One might infer that butterflies use the flowers as a source of food.

Sample Activity Take children on a mini fieldtrip to a tree on school property and have them prepare a list of observations about the ground at the base of the tree, the tree bark, and the leaves. Ask children to make inferences from their observations about the animals that may live in or near the tree (e.g., birds, insects, squirrels).

Hypothesizing and Predicting *Hypotheses* are often confused with *predictions*. A *hypothesis* is a proposed relationship put forth to explain a phenomenon. One might hypothesize that butterflies prefer yellow flowers. The *prediction* is the basis for an experiment. A prediction based on our hypothesis would be that if butterflies are presented with yellow flowers and white flowers, then the butterflies will land on the yellow flowers.

Sample Activity Ask your students what causes bread to mold. They might propose warm, moist air causes bread to mold. This is their hypothesis. Ask them to make a prediction to test their hypothesis (i.e., bread kept moist and warm will grow mold faster than bread that is kept dry and cool). They can design an experiment to test their prediction using baggies, bread, water, and specific temperatures. See the sample activity in the next section.

Inquiry Process Skills Used to Create an Experimental Model

Experiments test predictions. A good experiment should test one variable and keep all other conditions the same. Students often understand this in terms of a fair test. An unfair test results in confusion about what variable caused the results. (A word of caution: It is not necessary to do experiments in order to *do science*. I frequently hear preservice teachers describe science as experimentation. Experimentation is one method for testing predictions, but not all predictions can be tested by experimentation.)

Good experiments employ the following inquiry process skills:

- Predicting
- Identifying variables
    - Independent
    - Dependent
    - Controlled
- Designing experimental controls

Predicting A *prediction* is a specific forecast of a future observation or event. Predictions are based on observations, measurements, and inferences about relationships between observed variables. A prediction that is not based on evidence is only a guess. Accurate predictions result from careful observations and precise measurements.

Sample Activity Have children construct a questionnaire about breakfast cereal preference and gather data from all the classrooms in the school except one. Have students analyze their data and make a prediction about the outcome of the survey of the children in the last room before polling those children.

Identifying Variables *Variables* are factors that can make a difference in an investigation. Experimental design consists of one independent variable, one dependent variable, and several controlled variables:

- **Independent variable:** The independent variable is the variable being tested. It is the variable that the experimenter manipulates or changes. For example, if one were to follow through with an experiment to test the hypothesis that butterflies prefer yellow flowers, the independent variable is the color of the flowers.
- **Dependent variable:** The dependent variable is the change that is measured. It changes in response to the independent variable. In our example, the dependent variable would be the numbers of butterflies that are attracted to yellow or white flowers.
- **Controlled variables:** For an experiment to be informative, it must measure the effects of just one variable. Therefore, the only variables that change are the independent and dependent variables. All the other factors that could change must be kept the same or controlled. Referring to the sample experiment, the same butterflies and types of flowers should be used under the same conditions, such as location, lighting, time of day, and temperature.

Sample Activity Ask children whether bread will last longer (not become moldy) if it is kept at 4°C rather than at room temperature. Design an experiment by leaving one piece of bread in a plastic bag on a counter and one piece of bread in a plastic bag in a refrigerator at 4°C. Record the room temperature. Count the number of days until each piece of bread becomes moldy. The independent variable is temperature. The dependent variable is the time for the bread to become moldy. The controlled variables are bread from the same loaf, same size of bread pieces, same size and type of plastic bag, and the same handling procedures.

Interpreting Data The process of interpreting data involves finding patterns and trends based on the data collected in an investigation. We are constantly interpreting data when we read weather maps, watch the news on television, and look at photographs in newspapers and magazines. Data, used to justify an explanation, becomes evidence. It helps if students have had previous experience in observing, classifying, and measuring before the process of interpreting data is addressed.

Sample Activity Ask students to interpret the data in the graph shown of the distance from the starting point a bicyclist travels over a time period of 15 seconds.

- How far away from the starting point was the bike after 5 seconds? 10 seconds? 15 seconds?
- How fast was the bike traveling expressed as meters per second during the first 10 seconds?
- Infer what took place after 10 seconds.

Defining Operationally When students define operationally, they define terms in the context of their own experiences. That is, they assign meaning through an experience and then associate a term with the meaning.

Make the CASE *An Individual or Group Challenge*

The Problem

A colleague is working at teaching discovery-based lessons. She has asked you to review a brief video for her. She has three specific requests:

1. Look for evidence of three dimensional teaching: integrating science practices, disciplinary core ideas, and crosscutting concepts in ways that suggest her students are actively involved in discovery learning.
2. Do students have the opportunity to figure things out, make decisions, and make mistakes?
3. Critique her teaching. Is she providing too much, too little, or an appropriate amount of guidance? Is she thinking for or with the students? Is she telling or teaching?

Before you begin, write down some science practices and inquiry skills to guide your observation.

The Challenge

Summary

2.1 Create a vision for discovery learning in your classroom.

Keep in mind that students learn and teachers teach. When students discover, they make sense of the world. Their discoveries may not be new to the scientific community, but they are new and genuine discoveries for the students. Teachers are the knowledgeable others who create and guide the experiences for discovery to happen. Discovery teaching and learning are highly coordinated activities during which the teacher orchestrates experiences that facilitate discovery. Of course, there is no guarantee that students will discover what the teacher intends they learn. Therefore, discovery is not left to chance. Rather, teachers prepare learning experiences with purpose and intent that lead to a path of deeper understanding and sense-making through discovery.

2.2 Describe science practices and inquiry skills as they relate to learning science and engineering.

Science is a way of knowing based on evidence gained through inquiry. Young children need to start doing science just as young musicians need to start playing their instruments. Science practices and skills are the fabric of your science curriculum that will lead to a lifetime of discoveries for your students. Students who discover will make sense of their experiences to create explanations and design solutions. Left to their own devices, children's discovery is hit or miss. Under the guidance of an educator who is knowledgeable in both content and science practices, students will make discoveries that deepen their understanding of the natural world.

Knowing how to do science requires developing a set of skills that facilitate data collection and analysis. The skills support practices but differ from practices. Practices are accompanied by knowledge and understanding about how skills can be used to make sense of the world. Certain skills are conducive to creating descriptions, explanations, or experiments, but they all work together to help us generate knowledge and understanding.

On Your Own or in a Cooperative Group

1. The next time you are with young children, *observe* how they make sense of the world. What are their strategies for figuring out and seeking explanations?
2. Interview a child in your class. Present the child with a discrepant event: something with an unexpected outcome. Ask the child how he or she makes sense of the event, how he or she would figure it out. For example, draw an arrow on a piece of paper. Place the paper behind a drinking glass. Fill the glass with water and watch the arrow change directions.
3. Practice observing. Try being an active observer. Choose a place you want to observe more closely. For example, the next time you are in a restaurant, at a concert, in an art museum, at a sporting event, or even in your classroom, start by asking yourself the fundamental questions of observation. See what you notice that you did not notice before.
4. Some resistance to including the inquiry process skills comes from teachers who have not had much personal experience with science in college. To what extent did your college-level experience include opportunities to utilize the inquiry process skills?