New to This Edition

Since the last edition, the Next Generation Science Standards (NGSS)* have become available as a valuable resource to guide our science teaching. Chapters 1–9 have been revised keeping in mind the potential of the standards to guide science teaching and learning. As with the seventh edition, the eighth edition continues to address strategies to teach scientific ways of thinking and knowing. It strives to present practical classroom applications from the growing body of knowledge on how people learn that elementary school teachers can incorporate effectively into their teaching methods and strategies.

- Chapters 1–9 include Learning Outcomes to better guide the reader by highlighting the central focus of each chapter.
- Next Generation Science Standards (NGSS) are integrated throughout the book,
- Common Core State Standards (CCSS) are addressed in Chapter 7’s discussion of integrating science with other disciplines.
- Users of previous editions will notice restructuring of Chapters 3 and 4 to better unify theory and practice as well as a new lesson example that models how the NGSS might inform lesson planning.
- Chapter 5 recognizes the importance of accountable science talk to help children develop skills to argue effectively with evidence generated by sound scientific investigation. Questioning strategies, wait-time/think-time strategies, science talk, and the science circle are addressed.
- Perhaps most significant is the availability of the text as an e-book. As such, readers are able to access additional content.
- Embedded video, an e-text feature, enriches your experience with the text by allowing you to see real teachers, in real classrooms, as well as sharing their insights.

As with previous editions, this edition of Teaching Children Science benefits from the wonderful insights and suggestions of readers like you. Education, and especially teaching about teaching, is always a work in progress. Textbooks have always been a two-edged sword for me. On the one hand they provide a springboard for ideas; on the other they can be pedantic and boring to read. Traditionally, Teaching Children Science has striven to be conversational, engaging, and practical. Hopefully it is one of those textbooks that you will keep in your library and refer to for years to come. As was the case with prior editions, there are six major reasons for the continued success of this book:

*Next Generation Science Standards (NGSS) is a registered trademark of Achieve. Neither Achieve nor the lead states and partners that developed the Next Generation Science Standards was involved in the production of, and does not endorse, this product.
1. **Flexibility.** This single volume contains information about the three essential components of teacher preparation: science methods, science content, and science activities for children. In using this book, instructors and students alike can hone in on particular components and draw upon others as needed or desired.

2. **An inviting, engaging, and motivating style.** This is an upbeat book whose solid content is delivered in a way that makes it actually enjoyable to read. I still have negative feelings about the ponderous, unreadable, lifeless education methods texts that I used as a student and that still exist today. Many education texts are so massive and unmotivating. School classrooms need to be exciting, engaging places, and that won't happen if teachers use books whose heft and style inadvertently have the opposite effect.

3. **An inquiry-based and discovery-focused message.** This book presents a consistent and clear message about the type of learning experiences that teachers need to create. Namely, children learn best in classrooms in which they make discoveries (with the teacher’s strong guidance) using inquiry-based approaches.

4. **A constructivist approach.** There is little question that we create much of our own reality. One way of looking at how we integrate life experiences into our mental processes is provided by the theory of constructivism. When applied in the classroom, this theory guides teachers in thinking about what they are doing to help children get beyond scientific misconceptions and acquire more appropriate knowledge, skills, and values. Constructivism is used as a guiding principle throughout the book.

5. **A wealth of information.** As noted earlier, this book provides the three essential components for teacher preparation: methods, content, and activities. Additional content information specific to teaching about topics in the earth/space, life, and physical sciences is provided. As educators, we are challenged not only to understand science, but to help naïve learners grasp foundational scientific concepts that they can build upon as they grow intellectually. This text is designed to help us, as educators, create learning experiences that help students construct the fundamental concepts of science that will provide a strong foundation on the path to scientific literacy. It’s all here. Seek and you will find!

6. **References to standards.** “If you don’t know where you’re going, you’ll end up someplace else.” All of us who teach children science need some direction, and the best current direction is provided by the Next Generation Science Standards (NGSS). References to curriculum, unit, and lesson planning have been modified in light of the NGSS throughout the text.

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**How This Book Is Organized**

- **Part One: Strategies and Techniques**

  Again, the first nine chapters of this book deal with major topics that will shape what you teach, how you teach, and how you interact with children. They provide the basic “how-to-do-it” information for teaching science. To help focus your reading and discussion in these chapters, keep in mind that each has a consistent format that includes these components:

  - **Text:** A discussion of specific content-related topics
Contents

Preface

Parts Two through Four: Methods, Content, and Activities for Teaching Science and Technology Units

Each part opens with an introduction that provides background information about the field of science at hand: the earth/space sciences (Part Two), the life sciences (Part Three), or the physical sciences (Part Four). In each part, a section called History and Nature looks at careers in science, key events in the development of the field, and the lives of real women and men who helped shape that development. Another section called Personal and Social Implications reviews issues of personal and community health as well as the hazards, risks, and benefits that go along with scientific development. A final section, Technology: Its Nature and Impact, discusses and illustrates specific developments and considers the long-term implications of technology for our world.

Following each content section, you will find chapters (Chapters 12, 15, and 18) that integrate the unit and lesson planning strategies addressed in Part One. These chapters provide starter ideas and inquiry questions along with suggested activities, WebQuest demonstrations, in-class learning centers, bulletin boards, field trips, and cooperative learning projects. Although the lesson ideas suggest motivations and activities, it is up to you to mold them into engagements and explorations that create learning experiences rich in content for your students. Sample lessons illustrate how the lesson ideas and activities might be developed into an entire lesson.

Pearson eText

The eText for this title is an affordable, interactive version of the print text that includes videos, pop-up content, and links to additional information. The play button appears where video is available, while hyperlinked words provide access to pop-ups and other related websites.

To learn more about the enhanced Pearson eText, go to www.pearsonhighered.com/etextbooks.

By now, you are familiar with the content and organization of this eighth edition of Teaching Children Science, and I hope you are eager to dive into it! Use it now, during your teacher preparation, as a textbook and then later, in your years as a teacher, as a trusted and valued resource. You may also find useful another book written by Joseph Abruscato for pre- and in-service teachers called Whizbangers and Wonderments: Science Activities for Young People (Alyn and Bacon).
Instructor Resources

The following supplements to the textbook are available for download under the “Educa-
tor” tab at www.pearsonhighered.com. Simply enter the author, title, or ISBN, and 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 (0-13-357414-8) provides activity ideas for class
  sessions, as well as multiple choice quizzes.

● PowerPoint™ Presentations
  Ideal for lecture presentations or student handouts, PowerPoint™ Presentations
  (0-13-357424-5) for each chapter include key concept summaries.

Acknowledgments

Many people have shaped its content, directly and indirectly. Most of all I would like to
acknowledge Joseph Abruscato, who passed away since the last edition. 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 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 those who have reviewed this edition of Teaching Children Science
for sharing their expertise and valuable insights: Shirley Winn, Murray State University;
Donna Bennett, California State University, Fullerton; Michelle Smith, Cameron Statue
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D. D.
The whoosh and locomotive roar of a powerful tornado, tossing about cars and flattening houses; the careful maneuvering of a brightly colored lady bug, 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 one method for doing 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 have fun learning science.

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 construct their own scientific knowledge? You also need to know what to teach (as well as what not to teach) and how to teach it. What is the state of science education, and 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 what can you do to adapt science activities for children who come from diverse cultural backgrounds or have special needs and abilities? Finally, you need to know how and when to assess children’s progress in meaningful ways.

The chapters in Part One (Chapters 1–9) address these questions and more. 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 Parts Two, Three, and Four, respectively. I encourage you to use this book in a manner that fits your learning style. Some students prefer to go directly to the content and activities and refer back to the theory as needed. Other students opt to familiarize themselves with the theory first and then put it in practice.

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!
Inquiry: The Path; Discovery: The Destination

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

1.1 Defend the statement that children, although curious, are not young scientists.

1.2 State the criteria that distinguish science from other ways of knowing.

1.3 Describe the relationships among science, technology, and engineering.

1.4 Use the fundamental questions of inquiry as a framework for knowing what to do when you don’t have an answer.

**GETTING STARTED**

A man lives on the twelfth floor of an apartment building. Every morning he takes the elevator down to the lobby and leaves the building. In the evening, he gets into the elevator, and, if there is someone else in the elevator—or if it is raining that day—he goes back to his floor directly. Otherwise, he goes to the tenth floor and walks up two flights of stairs to his apartment.¹
Can you explain why the man sometimes takes the elevator directly to the twelfth floor while at other times he takes it to the tenth floor and walks two flights? You may have seen this puzzle or similar ones, known as lateral thinking puzzles. You may wonder what this has to do with science.

Science seeks explanations to our everyday questions and offers us strategies for knowing what to do when we don’t have an answer. Consider how you tried to solve the puzzle. Did your mind go blank? Were you wondering where to begin? Did you know what questions to ask? Science teaching means teaching children what to do when they do not have the answer. Science thinking skills are the tools of discovery. By teaching your students how to use the tools of discovery, you will start them on a path of exploration where they will no longer be restricted by memorizing what others have discovered, but they will use their skills to make their own discoveries and keep pace with an ever-changing world. Watch students and teachers learning what to do when they don’t have the answer.

As elementary school teachers, you provide the most important link to start the children on the path to discovery. This chapter is about understanding the practical thinking strategies and skills that you can teach your students to embark on this journey. We will revisit the puzzle later in the chapter.

**Shaping Young Minds: A Wonderful and Awe-Inspiring Opportunity**

**A Chance to Touch Tomorrow**

*All of the flowers  
Of all of the future  
Are in the seeds of today.*  
—Source unknown

As you awake and start your new day, I’d like you to think of these three short lines as your gentle alarm. I want them to remind you of the enormous potential that lies in the hearts and minds of children. You are their temporary mindstretcher and caretaker. You are the overseer of the seeds and the creator of the rich soil that will nurture these seeds of new tomorrows to grow. What and how you teach children will race ahead of you to a time you will never know. The responsibility is enormous. It will take dedication, energy, and the unwavering belief that what you do and how you do it will actually change lives. What and how you teach will touch tomorrow. You will touch tomorrow.

**Your Children: Curious, Aspiring Scientists Who Need Guidance and Direction**

Children love to touch! At least, most children do. They also like to look at things, to smell them, to move them about, and to twist and turn them. Children want to know
how things work, and, like squirrels, they sometimes horde papers, science materials, and wildlife in their desks for more detailed inspection later.

At the heart of science is this natural human desire to explore the world that is directly reachable as well as those worlds that are hard to reach. The children in your classroom are, in this respect, very much like scientists. In fact, some would say that they are more like scientists than are teenagers or even college students!

However, do not assume that children are adult scientists in small bodies. Curiosity is a wonderful attribute and precursor of scientific thinking, but in order to truly become scientific thinkers, children must develop habits of mind that go beyond their natural curiosity. Scientific inquiry requires careful, active observations of the details and connections of systems and events that we encounter, which often go unnoticed by casual observers. As the famous physicist Richard Feynman once said, "The first principle is that you must not fool yourself and you are the easiest person to fool." Your elementary school children will tend to have boundless energy and curiosity. Your job will be to make sure that you deliver a curriculum that capitalizes on both and encourages them to become active observers and scientific thinkers.

As elementary school teachers, you will be entrusted with the responsibility of developing the most important organ in the individual: the brain. The title of a book written by James Zull, *The Art of Changing the Brain*, aptly suggests the magnitude of the career you have chosen. As a teacher, you will be responsible for shaping thousands of young minds. You will actually influence the creation of synapses and neural networks associated with thinking and reasoning. As the gatekeepers of learning, you can start children on the path to a lifetime of discovery by teaching them the thinking skills and science practices they need to explore the unknown.

**The Developing Brain**

The child's brain is not simply a small adult brain. It is undergoing important stages of development. The brain is equipped with an abundance of neurons (specialized
brain cells) at birth. As one learns, the connections among neurons (synapses) increase, and the ability of brain cells to transmit signals improves (myelination). The experiences you provide children can stimulate and strengthen connections among brain cells that reinforce learning. Unused synapses are pruned, whereas useful synapses are reinforced and developed. As elementary school teachers, you work with children at a time when their brains are undergoing significant developments that will last a lifetime.

Science: What Is It, Really?

Science is a way of knowing. It seeks explanations of the natural world. It consists of the following components:

- A systematic quest for explanations based on evidence
- The dynamic body of knowledge generated through a systematic quest for explanations

Most important to remember is that science is a way of knowing that uses evidence to support its claims. Unfortunately, science is often associated solely with its outcomes, which is 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 a computer can find information. Science involves the process of generating information. Science teaches us what to do when we do not have the answer. It is a systematic search with a variety of strategies that results in a dynamic body of scientific knowledge. Pluto is no longer considered a planet, Earth is no longer considered flat. Is caffeine good for us or not? The scientific body of knowledge is not static.

As an elementary school science teacher, you will teach process skills, values, and attitudes associated with seeking scientific explanations as well as the body of knowledge that constitutes 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 to create and keep complex mental models of a system in their minds and imagine what would happen when different elements 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.

● What Does Scientific Thinking Look Like?

Do you recall reading about the scientific method in your high school, or perhaps even middle school, science textbook? 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 this may be true in some cases, it is not the only way science is done, and it is not a straightforward and linear process. Scientific thinking typically involves asking questions or making claims, collecting evidence, making connections, and verifying claims—all in an effort to seek a reasonable explanation based on evidence.

In order to teach scientific thinking, it is helpful to identify a framework for scientific thinking that is practical and teachable. There are several frameworks one can use. I find it helpful to think of a simple progression of inquiry consisting of three models. The models are descriptive, explanatory, and verifiable.3

**Descriptive Model**  In order to explain a phenomenon, it helps to have a good description of the situation. Learning how to make good descriptions is a hallmark of elementary science. It is no small accomplishment to be a good observer. Good scientists recognize the distinction between looking and observing. Merely looking is a passive event; observing is an active event that is deliberate and systematic. Think of a detective at a crime scene, methodically looking for and finding clues that a casual observer overlooks. The observational skills that you teach your students differ only with respect to levels of sophistication and technology from the observational skills used by experienced
scientists. Scientists who use electron microscopes to measure distances in angstroms ask the same descriptive questions as first-graders who use rulers to measure distances in centimeters. Descriptive models help us understand what we are dealing with. They may suggest possible explanations or reveal gaps in our knowledge.

**Explanatory Model**  The explanatory model consists of claims based on prior knowledge and evidence. Evidence can be gathered in a variety of ways. It can be field based, such as recording the rainfall over a designated period of time. It can also be experimental. Designing a good experiment requires a prediction, the use of independent and dependent variables, and the use of controls.

**Verifiable Model**  The proposed explanations need to be verified. Experiments or field observations generate evidence that can be used to reinforce or refine explanations. Gathering evidence often leads to new observations, which yield deeper insights that modify descriptive models and identify new questions. Thus science is a dynamic, ongoing process.

Note that these models are one way to represent a progression of inquiry to inform our teaching. It is important to note that these models are not necessarily sequential. We often go back and forth among the models and develop them simultaneously.

**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. Explanations are tentative and subject to change, however scientists do not change their explanations on a whim. They rely on an accumulation of evidence that is convincing enough to modify their explanations. This requires a critical view of the evidence by the scientific community. One of the most famous examples is spontaneous generation, the belief that life can emerge from non-living 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.

**Science as a Set of Values**

Although there are many values you can emphasize as you help children experience science processes and learn content, 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 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.

There is, then, an underlying order to the processes and content of science. In their search for explanations, scientists gather information and then organize it. It is this order that allows 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.

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 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 is vital if knowledge is to grow. Without extensive communication, progress would be greatly limited.

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 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.

**Developing Psychomotor Skills** You might not think of your classroom as a place where children learn to coordinate what their minds will 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 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\textsubscript{2} emissions and global warming trends. However, at some time in their lives, they will be concerned about societal issues. And to be responsible citizens, they will need to address such issues with wisdom—wisdom based on a foundation of knowledge constructed many years earlier. Perhaps some of that knowledge will be gained in your classroom.

With your guidance, children will learn that real inquiry requires gathering evidence before reaching a conclusion. Hopefully, learning to gather knowledge systematically and to reach carefully thought-out conclusions will be skills they apply as they confront 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.

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**Scientific Literacy: Your Science Teaching Will Create It**

Add STES to the list of acronyms you carry in your brain. It stands for Science, Technology, Engineering, and Society, a catchphrase that represents what average citizens should know about three things that affect them and their society constantly: science, technology, and engineering. In short, STES is related to creating citizens who are scientifically literate.

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**REALITY check**

**What Would You Do?**

During a school committee meeting to discuss the elementary science program, a committee member suggests, “While science is important, it should not be emphasized at the elementary level, since the children need to learn reading, math, and writing during these formative years. Science, after all, requires memorization of a rather extensive amount of factual knowledge, which should be saved for the middle and high school years. It has little to offer developing minds of elementary school students.” For this reason, she argues, minimal time should be allotted to elementary science education.

As an elementary school teacher at the meeting, you are asked your opinion on the matter. How would you respond to this school committee member’s suggestion?
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 knowing 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. For example, some people argue that humans have little or no effect on climate change, while others argue that humans have a significant impact on climate change. The scientifically literate person, while not necessarily understanding all of the science behind climate change, will ask questions about the evidence used, the quality of the evidence, how it was collected, and whether the claimants could have a bias toward a particular outcome. 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.

**Gender and 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 homework and also brings home creepy things.4

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 male.

One of my favorite classroom activities is to ask each student to draw a picture of a scientist at work (see Figure 1.1). In most cases the scientist is depicted as a bespectacled, old, white male with a slightly mad glint in his eyes, having a very bad hair day. While it may seem amusing, the real harm of this stereotype lies in the fact that it 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.

**Figure 1.1** Children’s Illustrations of Scientists
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 cultural and linguistic diversity and addresses gender inequities, 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 Renee, 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 Renee 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 Renee, who contorts her face into a disgusted grimace and exclaims, “Yuck... get those things away from me, Ashley! I don't like worms. I hope you are not thinking about bringing them into my classroom.” Ashley's smile vanishes as she walks quietly to the grassy area next to the school and dumps the worms on the soft ground.

Although this scenario may seem somewhat exaggerated, similar scenes have taken place in too many schoolyards and classrooms. Ashley did not learn anything about worms or their role in the ecosystem of the garden. Much worse, Ashley may take home the lesson that adult, educated women should not like worms or be curious about nature. Research reveals that children in the United States generally think of scientists as white males, most often involved in work in a laboratory. While this notion may be changing, we must continue to do all we can to inspire children to understand that science is not relegated to a any particular gender, race, or ethnicity. Teachers need to promote images of scientists that reflect a diversity of people so all students have the opportunity to envision themselves as scientists.

**Connecting Technology and Engineering in Your Teaching**

What do these terms have in common: video games, solar panels, prescription drugs, fuel cells, soft contact lenses, electric cars, CAT scans, X-ray treatment for cancer, and ramen noodles (noodle-like 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 smart phones we are using today will likely be outdated within the year. 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? Watch third-graders designing, constructing, and testing a waterwheel. Note their engagement and creativity as they integrate science, technology, and engineering. Describe the science and engineering practices the children exhibit. Some building projects that are easily integrated into technology/engineering design projects are listed below.

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. Try Make the Case to better understand your perspectives on science, technology, and engineering.

Preparing to Teach for Learning and Discovery

“How do we know what we know?”

This certainly seems like a simple question when you look at it. I could even develop a rather complicated answer for it, if I were so disposed—but I won’t! I suggest that we know what we know because we have made discoveries, and we have made those
discoveries through inquiry. You made discoveries yesterday, you will make discoveries today, and you will make discoveries tomorrow. In fact, you are making discoveries as you read the printed words on these pages.

*Discovery*, which is part of the subtitle of this text (*A Discovery Approach*), is the journey on which you will lead your students to deeper understanding of the natural world. It is our discoveries that make us what we are. They underlie what we think, feel, and do.

Now the question is, “How do you make those discoveries?” Although there are many paths to discovery, this text is based on the path called *inquiry*. In fact, the paths of inquiry are different for bakers, accountants, cosmetologists, auto mechanics, and shepherds. We will focus on the way scientists inquire because we want children to make their science-related discoveries in the same way that real scientists do.

### Inquiry: The Path Children Will Take toward Discovery

“Do chickens have teeth?”

“Why does a lightbulb get hot?”

“Why are there holes in cheese?”

“Why can’t we send the new baby back?”

Questions, questions, and more questions! Asking questions is what makes humans what we are. We seem to have a genetic urge to make sense of our surroundings, and this constant questioning is our most powerful tool. When you teach science, that is the tool
all children will bring to you—the urge to question their surroundings—and so it will provide the foundation for much of your teaching.

Science seeks explanations, through a process of inquiry. Inquiry often begins with questions. The challenge is to know what questions to ask. How often have you been in a new situation and heard, “If you have any questions, just ask,” but you don’t know where to begin? In these cases, it is good to have some big questions to guide and structure your inquiry. I liken these questions to solving a puzzle. You have a vision of the big picture given to you on the box, but you don’t know how the 1000 pieces in a pile go together to make that picture. The first step is to identify the pieces as well as possible. You do so by examining the properties of the puzzle pieces: color, shape, and size. You might find the border pieces first because those are easy to identify. They help to define the boundaries of the puzzle. Next you look for possible relationships among the pieces. How do they fit together? 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.6

This process can be guided by fundamental questions of inquiry. They are general questions to get started on the journey of discovery. They can be represented using more general language, as suggested in Table 1.2.

<table>
<thead>
<tr>
<th>Puzzle Terms</th>
<th>Generalized Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the pieces of the puzzle?</td>
<td>What are the elements of the system?</td>
</tr>
<tr>
<td>What are the properties of the pieces?</td>
<td>What are the properties of the elements?</td>
</tr>
<tr>
<td>What are the boundaries of the puzzle?</td>
<td>What is the context or background space of the system?</td>
</tr>
<tr>
<td>How do the pieces relate to each other?</td>
<td>What are the relationships (connections) among the elements?</td>
</tr>
<tr>
<td>What picture emerges when the pieces are put together?</td>
<td>What are the emergent properties (characteristics) of the system?</td>
</tr>
</tbody>
</table>

These questions guide initial observations and enable inquirers to be active observers. Often during class, teachers ask students to make observations without first teaching them how to observe. They just expect the students to look. But 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. These fundamental questions of inquiry guide observation. They provide a starting point to organize our thoughts. Let’s use the puzzler at the beginning of the chapter as an example of how to use the fundamental questions of inquiry. Recall the puzzle: A man lives on the twelfth floor of an apartment building. Every morning he takes the elevator down to the lobby and leaves the building. In the evening, he gets into the elevator, and, if there is someone else in the elevator—or if it is raining that day—he goes back to his floor directly. Otherwise, he goes to the tenth floor and walks up two flights of stairs to his apartment.7

The first inclination of most people is to attempt to answer the question right away. Scientific thinking requires us to take a systematic approach, beginning with a descriptive model. In other words, we need to get our minds around the event to understand what we are dealing with before we attempt an explanation. We begin by describing the situation using the fundamental questions of inquiry:
• What are the elements?
  Man, elevator, floors, stairs, apartment, other people

• What do we know about the properties of the elements?
  The apartment has at least 12 floors. Note that we do not know much about
  the properties of the man, the elevator, or other people in the elevator. Be-
  cause this is a word problem, the best we can do is infer their properties. If we
  could actually observe the events or model and reenact them, we could learn
  more about their properties. Often scientific investigations consist of gather-
  ing this type of descriptive data. Asking the question about properties helps
  identify what needs to be known.

• What is the background space?
  The events take place in the morning and evening in an apartment building.
  Sometimes it is raining.

• Rules of interaction
  This is what we know:
  Man goes down 12 floors in the elevator
  Man goes up to the tenth floor in the elevator
  Man walks up two flights of stairs
  Man goes to the twelfth floor directly from the lobby if it is raining outside or
  if there is someone else in the elevator with him.

• Emergent properties
  Man moves between the lobby and his apartment

At this point, you probably do not have enough information to explain the man’s
behavior, but you do have a better descriptive model. Much like a detective solving a
mystery, your systematic analysis of the situation enables you to ask meaningful questions
to deepen your descriptive model. Let’s imagine (model) the scene as it unfolds, based on
our descriptive model and our prior knowledge. Our knowledge of elevators suggests that
there must be a panel of buttons on the wall. The rules of interaction between the man
and the elevator suggest that the doors open, he steps into the elevator, and he pushes the
lobby button on the panel. Doing so brings him to the lobby. In the evening, the process
is repeated. Except this time we know that he presses the tenth floor button if he is alone,
travels to the tenth floor where he exits the elevator, and walks two flights to the twelfth
floor. As we continue to run the model in our minds, we imagine the situation with some-
one else in the elevator. In this situation, someone has to push the twelfth floor button,
and the man travels to the twelfth floor, where he exits. When it is raining, the man can
ride the elevator to the twelfth floor on his own.

Do you have an explanation yet? Don’t worry if you did not arrive at the correct expla-
nation (see the end of the chapter). Although identifying the best explanation is the desired
outcome, it is the process that is important in this example. That is why science inquiry is
called research, and not simply search; we must seek answers and try again to seek them.
Hopefully you realize that a scientific approach is a strategy that keeps you moving toward a
better explanation. Begin by teaching your students to make good descriptive models.

• National, State, and Local Standards:
  They Will Light Your Way

Have you ever dreamt that you were lost in a forest and had no idea of how to get
out? You might remember such a dream as an overpowering nightmare from which you
awoke filled with dread and hopelessness.
The thought of teaching children science may be similarly overwhelming, but it should not leave you feeling hopeless. You should feel uplifted! In the bad dream, you are alone. In the real world of teaching children science, you are not. Many people have spent their entire professional lives developing goals, objectives, procedures, and materials for science teaching. You will have access to the fruits of all of their labor. For now, think about just one aspect of all of this: the goals and objectives of your science teaching. Again, you will not have to invent them all yourself! The scientific and education communities have worked very hard to articulate guidelines of what children should know about science and engineering and generally when they should learn it. The guidelines are called the Next Generation Science Standards (NGSS).* They represent the most recent effort to identify what K–12 children should experience about science.

While the NGSS function like a lighthouse that points to the final destination, they do not set the course. It is up to you and your district or department team to determine how the students will reach the standards. Know that the NGSS represent one among many guides available to help determine what science to teach. Individual states, provinces, and local communities also have developed standards and curriculum maps. Sometimes called frameworks, they provide varying degrees of guidance in the forms of content, teaching, and sample lessons. In the information age, your biggest challenge will not be to create original science lessons as much as it will be to recognize and choose effective, inquiry-based science lessons. No two classes and teachers are exactly alike; therefore, you will need to adapt and revise each lesson to best fit your teaching style and the needs of the children in your class.

Rest assured that you are not lost and alone in the forest. The path you will take as you lead children to discovery is well marked. You will have many resources as you guide children to explore, inquire, and discover. You are definitely not alone. Sleep well and then awake and seize the day!

**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 eight chapters), you will learn basic

*Next Generation Science Standards (NGSS) is a registered trademark of Achieve. Neither Achieve nor the lead states and partners that developed the Next Generation Science Standards was involved in the production of, and does not endorse, this product.
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 chapters in those parts, you will find unit and lesson “starter ideas,” activities and demonstrations, and even basic science content for your reference 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 Shaping Young Minds: A Wonderful and Awe-Inspiring Opportunity
You will be teaching children not only science but also strategies for thinking and knowing what to do when they do not have the answer by creating a classroom environment that embraces and directs children’s natural curiosity. You will guide children to develop habits of mind necessary to be active and curious observers, to make claims, gather evidence, and generate explanations. In doing so, your students will use and develop inquiry process skills, positive attitudes toward science, and abilities to do science.

1.2 Understanding Science: What Is It, Really?
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 represent a systematic, well-thought-out approach.

Five fundamental questions of inquiry provide a structure for beginning inquiry:

1. What are the elements of the system?
2. What are the properties of the elements?
3. What is the context or background space of the system?
4. What are the relationships (connections) among the elements?
5. What are the emergent properties (characteristics) of the system?

1.3 Connecting Science, Technology, and Engineering in Your Teaching
Technology, science, and engineering are integrally connected. Technology is the application of science to serve human needs. Engineering is the application of science to serve human needs through design and development processes that lead to new technologies. 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.

1.4 Preparing to Teach for Learning and Discovery
The challenges of teaching children science will require you to use a variety of resources, including units and lessons that you plan yourself, science resource books, and the Internet. Organizations such as the National Academy of Sciences and the American Association for the Advancement of Science as well as local science standards and frameworks will also be your guide as you plan learning experiences in which children learn to seek explanations through inquiry and discovery.
GOING FURTHER

On Your Own

1. Think about when you have observed children in elementary, middle, or high school exploring, doing inquiry, and making discoveries, or recall your own experiences in science. Provide any examples that you can, including examples of students using the inquiry process skills (e.g., observing, interpreting data, etc.).

2. Consider your present feelings about teaching children science and identify the factors that have influenced your attitudes.

3. If possible, interview an elementary school teacher to find out how he or she would answer such questions as these: How do you feel about teaching children inquiry-based, discovery-focused science? What do children think science is? What materials for learning science are available in your classroom or school? Do you feel well prepared to teach science? Why or why not?

4. Research the role that science, engineering, and technology have played in shaping present-day society. Consider such questions as these: Would society be better served if science were pursued only for the sake of the technology that results from it? Do scientists and engineers occupy a prestigious position in modern society? What responsibility do scientists and engineers have for communicating the results of their work in a way that is understandable to the public?

On Your Own or in a Cooperative Learning Group

5. Discuss the role models that your parents, teachers, textbooks, and the media offered you in elementary school. Can you recall your level of career awareness as an elementary student? What did you want to become? Why? If you are a woman, what factors tended to turn you toward or away from a scientific career? If you are a man, what stereotypes, if any, did you have about women and careers in science and technology?

RESOURCES FOR DISCOVERY LEARNING

Internet Resources

- Next Generation Science Standards: www.nextgenscience.org
- National Science Teachers Association: www.nsta.org
- Project 2061 Overview: www.project2061.org

Print Resources

Suggested Readings


Chapter 1 • Inquiry: The Path; Discovery: The Destination


Lightbody, Mary. “Countering Gender Bias in the Media.” Science Scope 25, no. 6 (March 2002): 40–42.


Notes


Answer to the elevator puzzler: The man is not tall enough to press the twelfth-floor button when he is alone. However, someone else can press it for him when other people are in the elevator. When it is raining, he can push the twelfth floor button with an umbrella.
Constructing Knowledge and Discovering Meaning: How Children Learn Science

2.1 Identify and describe five big ideas about how children learn science.

2.2 Describe three constructivist principles and their connections to teaching and learning science.

2.3 Use science standards to inform you about science knowledge students need to construct.

2.4 Justify the need to be sensitive to a range of learning styles.

GETTING STARTED

Suppose one of your fourth-grade students wonders aloud, “Why can’t it be summer every day? Summer is such a wonderful time of year!” Before you provide your student with the explanation of why the seasons change, take a moment to think about your response.

Consider that graduates were asked to explain the reason for the seasons during commencement at Harvard University in 1987.1 You
may be surprised to learn that 21 out of 23 graduates answered incorrectly. Most people offered the common misconception that the seasons are caused by the distance of Earth from the Sun. It is likely that several of the college graduates were told the correct reason for the seasons at some point in their academic careers. The question we need to ask is did they really learn the reason for the seasons?

So what is learning, really? Learning is the result of deepening or changing our mental models to more accurately describe and explain phenomena. It is usable knowledge that can be recognized and applied (transferred) in a novel context. According to the National Research Council, “Experts' knowledge is connected and organized around important concepts (e.g., Newton's second law of motion); it is 'conditionalized' to specify the contexts in which it is applicable; it supports understanding and transfer (to other contexts) rather than only the ability to remember.” Learning suggests that we deepen our understanding by modifying our existing knowledge. To truly understand the reason for the seasons, one first needs to understand the warming effects of indirect light as opposed to direct light on a surface area and transfer this understanding to the interaction of sunlight on a planet tilted at approximately 23 degrees as it revolves around the Sun.

Learning doesn’t happen only for children, and it doesn’t happen only in school. Learning is an ongoing process in which the learner integrates new knowledge with previous knowledge and discovers new ways of thinking, acting, and feeling. We are always constructing new meanings in this way. I am always learning, you are always learning, and right now, somewhere a child is learning that it doesn’t matter whether a corn seed is planted upside down or right side up. That child is learning that in the proper environment, new shoots, like young children, grow toward the light.

What We Understand about How Children Learn Science

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. While these traditional theories guided our perceptions of how children learn, we have since learned that young children can think both concretely and abstractly. Children do not stick to a single predetermined timeline for cognitive development. There is variation among children in their capacity to think and understand at higher levels of thinking. We do know that we can help children develop capacities to think and learn by providing stimulating and thoughtful learning experiences. Much research on how children learn science has been summarized by the National Academy of Sciences in publications such as Taking Science to School: Learning and Teaching Science in Grades K–8 and How Students Learn: Science in the Classroom.
I highly recommend that you read these selections. However, I realize that you may not have the inclination or the time, as you are likely immersed in classes and teaching practice. Therefore, I briefly highlight some of the big ideas suggested by research on how children learn science.

- **Science Is a Way of Knowing Based on Evidence**
  Keep this very simple thought in mind and use it as a guide whenever you plan science learning experiences for your children: Science is about seeking explanations based on evidence. *Evidence* is the key term. The fundamental question you must ask when you are teaching or preparing to teach science is how your students are using evidence to understand the natural world.

- **Children Come to You with Prior Knowledge about Science**
  Children have ideas and prior experiences that inform their way of knowing. At times their prior knowledge leads them on the path to deeper misconception. Other times their prior knowledge provides a good foundation that you can build upon to deepen their understanding. In both cases, prior knowledge and beliefs are highly resistant to change. You can identify children's prior knowledge and use it to inform your teaching. I like to call this *pedagogical judo*. Judo redirects energy in the individual (usually the opponent, although I do not want you to think of your students as opponents). You can redirect your students’ cognitive energy to foster scientific ways of knowing. Listen to Dr. Jim Cummins speak about the role of prior knowledge in learning.

- **Science, Like All Other Learning, Is a Progression**
  Learning science is an ongoing process. We hear talk about “covering” topics. Covering implies that we put a lid on it! Nothing is learned as a one-off experience. We may experience “aha!” moments, but they are usually benchmarks in an ongoing learning process that has been going on for years. We need time to process information. That is why you will hear the term *learning progressions* in reference to science education. Learning progressions imply the deliberate and coordinated development of learning over time—a long time such as an academic year, a K–12 experience, or a lifetime. So when you are tasked with teaching a unit on electricity to your fourth-graders, remember that you have the privilege to guide them on one part of the journey. You do not have to teach all there is to know about electricity to your class. Advance their understanding from where they began in the fall and prepare them to make more gains with their next teacher.

- **Children Learn Science by Doing Science**
  What does it mean to do science? In one respect, this is easy to answer. Science is about discovering and understanding the world, based on evidence. It is a process of logical reasoning about evidence. In another respect, it is not so easy to answer. Practicing science is more than collecting, analyzing, and using evidence to support explanations. It also includes perspectives that characterize the nature of science, including beliefs that science is dynamic and tentative, and values such as skepticism, imagination, and peer critique. The nature of science is acculturated as much as it is learned.
● There Is Variation in the Rate of Cognitive Development among Children

Our industrialized roots continue to permeate our educational system, dictating learning goals based on children's date of birth. It is as though they have a “teach by” stamp tattooed on their foreheads. The developmental research community no longer accepts the view that there is a predetermined age when all elementary children can reason and think abstractly. Children, especially elementary and middle school children, grow cognitively as well as physically at different rates. As teachers, we have opportunities to guide that development by orchestrating learning experiences targeted at developing scientific ways of thinking and the science practices associated with them.

Constructivism: A Modern View of How Children Learn Science

● What Is Constructivism?

*Constructivism* is a theory of human learning that is rooted in cognitive psychology and, to a lesser extent, behavioral psychology. It provides modern science teachers invaluable guidance. In fact, if you grasp the essential principles of constructivism, you will find it much easier to answer the two questions that will always be running through your mind as you approach a topic: *What should I teach?* and *How should I teach?*

● Three Constructivist Principles to Guide Your Planning and Teaching

**Naive Conceptions**  A person never really knows the world as it is. Each person constructs beliefs about what is real. Your experience with children probably has already taught you that not everything a child believes or knows is true. For example, Tom may believe that sweaters keep him warm because sweaters are warm. Uncle Harry, who lives with Tom’s family, has told him many times to wear a warm sweater on a cool day. The belief that a sweater is warm is an example of a naive conception: an idea that does not fit reality when its validity is checked. Children and adults have many naive conceptions, and it is extremely difficult for a teacher to help a child construct new understandings if the child’s naive conceptions filter out new experiences. Look at the statements in Figure 2.1. Can you tell if they are naive or informed?

---

**Figure 2.1**  Naive or Informed

<table>
<thead>
<tr>
<th>T / F</th>
<th>Evolution is a theory about the origin of life.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T / F</td>
<td>Stars appear in the same place in the sky every night.</td>
</tr>
<tr>
<td>T / F</td>
<td>Mass is the same as weight.</td>
</tr>
<tr>
<td>T / F</td>
<td>Heavy objects fall faster than light objects.</td>
</tr>
<tr>
<td>T / F</td>
<td>There is no gravity in outer space.</td>
</tr>
<tr>
<td>T / F</td>
<td>Objects sink in water if they are denser than water.</td>
</tr>
</tbody>
</table>
Assimilating and Accommodating New Learning  Much of teaching is really reteaching and challenging mental models with discrepant events, which lead to assimilation or accommodation. Different, but complementary to one another, these last two principles both address ways in which a child tries to fit new ideas into those already in place. 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 Earth is round (which is also incorrect but commonly taught; 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 that Earth is round, 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. Cognitive psychologists use the term assimilation to describe the reconciliation of new experiences and data with present understanding so that the new data support and deepen but do not change their fundamental mental model.

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. Assimilation and accommodation are not mutually exclusive. They often complement each other in the learning process.

Constructivism focuses on the interplay between what the child already knows and the experiences the teacher provides. The conceptions and naive conceptions with which a child encounters a new experience make a very real difference in what the child will learn. Figure 2.2 identifies some practical strategies for identifying children's prior knowledge.

Contributions of Neuroscience  Developments in the technology of cognitive neuroscience provide windows into the workings of the human brain like never before. Teachers in the twenty-first century need to become increasingly familiar with ways in which the brain processes information to understand the implications for learning. Educators need to know how to interpret, critically assess, and appropriately implement the emerging research on the neuroscience of thinking and learning. A word of caution about neuroscience: While neuroscience increasingly informs education, much research remains to be done. Use research from neuroscience to inform your educational practice judiciously. Let it be one of several data points to guide your practice. It is likely that neuroscience will not change what good teachers already do; rather, it will inform why what they do works well.

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Chapter 2 • Constructing Knowledge and Discovering Meaning: How Children Learn Science

Figure 2.2 Constructivism for Your Science Classroom: Practical Applications

**Constructivism for Your Science Classroom**

1. Prior to a lesson or unit, ask your students what they think and believe about a topic, and organize their input with a simple graphic organizer on a piece of newsprint that can be kept in the class for the duration of the unit. Label one column “What we know” (to assess prior knowledge), and label the other column “What we want to learn” (to initiate the inquiry process). Enter the children’s initial thoughts, and then add a third column labeled “What we learned,” to be completed by the class over the course of the unit.

2. Develop some true/false questions about the topic. Children’s responses will give you a sense of their prior knowledge. Example:
   a. Water can move rocks. T/F
   b. Rocks never change. T/F
   c. All rocks are the same. T/F
   d. Some rocks can float. T/F

3. The Internet is also another way to get an idea of children’s common prior knowledge or misconceptions before you prepare a lesson. There are several sites that list common misconceptions available through search engines.

4. Probe prior knowledge with an authentic experience. For example, if the unit topic was weathering and erosion, you might want to show them a rock with evidence of weathering or take them out on the school grounds where there is a good example of weathering and erosion. Point out evidence that you know is the result of weathering and erosion (i.e., rock outcropping with cracks and splits and smaller rocks at the base). Wonder out loud how the smaller rocks got there, and ask the students for their explanations.

Ways to Support Your Constructivist Teaching

- **The Next Generation Science Standards**

  Here is a question for you: Do you know what *rebar* is? Oh, you don’t. Before I reveal its meaning, you must answer another question: Have you ever thought of becoming a construction worker instead of a science teacher? Perhaps you haven’t.

  Surprisingly, teaching children science has elements of the construction industry in it. For one thing, you want to build a foundation that will give your children the knowledge, skills, and attitudes to keep them interested and constantly learning about science, engineering and technology. Without that foundation, children will find it difficult, if not impossible, to add new layers of learning.

  That’s where rebar comes in. It is a thick strand of steel that runs within the concrete slabs of a foundation. You probably have seen rebar sticking out from chunks of broken concrete. The rebar strengthens the concrete so that the foundation is durable and can stand the test of time.

*Next Generation Science Standards (NGSS) is a registered trademark of Achieve. Neither Achieve nor the lead states and partners that developed the Next Generation Science Standards was involved in the production of, and does not endorse, this product.
Ways to Support Your Constructivist Teaching

Make the CASE  An Individual or Group Challenge

- The Problem
  Providing a rich learning environment for children may require the teacher to take them out of the traditional classroom occasionally and into the real world. Sometimes, it is difficult for new teachers to identify real-world experiences that will really improve children’s achievement in science.

- Assess Your Prior Knowledge and Beliefs
  What do you presently believe about the way in which children learn both in and out of the classroom?
  1. Children learn best from direct experience with natural objects and phenomena.
     ______ agree ________ disagree
     Your evidence: ________
     ______ agree ________ disagree
     Your evidence: ________
  3. A child’s prior knowledge and beliefs should be assessed before new experiences are introduced to ensure that the experiences will be meaningful.
     ______ agree ________ disagree
     Your evidence: ________
  4. Children have few misconceptions about the natural world.
     ______ agree ________ disagree
     Your evidence: ________
  5. For highly able children, it probably makes little difference whether direct or hands-on instruction is used in the classroom.
     ______ agree ________ disagree
     Your evidence: ________
  6. Because children progress through identifiable stages of development, teachers should provide experiences that fit only the stage of development indicated by the children’s age.
     ______ agree ________ disagree
     Your evidence: ________

- The Challenge
  Integrate your knowledge of how children learn into one paragraph that will provide a rationale for taking the children to locations beyond the school grounds. Your intention is to use this paragraph in a letter you will send (with your principal’s permission) to community leaders who may be willing to donate funds for this curriculum enrichment project.
The specific science content identified in the Next Generation Science Standards (NGSS) is our teaching “rebar.” The science practices, core ideas, and cross-cutting concepts in the NGSS will strengthen the foundation on which children will construct knowledge and discover meaning.

Let’s be more specific about how the NGSS will support and reinforce your constructivist teaching. I’ll discuss this support within the three guiding principles of constructivism presented earlier in this section.

**Naive Conceptions** The most basic support for this principle comes from the existence of the NGSS themselves. Since we finally have science standards, you, as a teacher, have something against which to compare students’ prior knowledge and beliefs. If you listen carefully to children, you’ll hear some amazing things about how they think the world works. Unfortunately, some of those beliefs are simply wrong!

What you need to do is first carefully study the standards to ascertain within which standard children’s inaccurate knowledge and misconceptions lie. Then you can take guidance from the chapters of this text and other resources to properly address the deficiencies.

Here is an example:

A child says: “I think that the Moon followed us when my mom walked me to Janet’s house for a sleepover.”

The misconception can be addressed by providing content and experiences related to the disciplinary core idea entitled Earth and the Solar System (ESS1.B), which provides insights regarding the core content elementary children should understand about the relationship of the moon to the Earth.

**Assimilation** The NGSS recognize inquiry as an integral component of science education supported by practices associated with good science. By creating science unit and lesson plans for children that are consistent with the methods advocated in this text, you will be infusing the curriculum with discovery experiences and activities that are based on careful science practices that support inquiry. Children will learn to confront the differences between what they believe and what they discover with their own senses. Your challenge is to teach them that firsthand, personally gathered knowledge must override incorrect beliefs.

Here are two examples:

A young child might say: “Magnets pull on everything.”

This misconception can be countered and replaced by having children actually do magnet activities in which they make discoveries to the contrary.

An older child might say: “It’s starting to get hot. Earth must be getting closer to the Sun.”

This misconception can be countered by doing an activity in which children use models to discover that the inclination of Earth varies the surface area upon which a given amount of sunlight falls. When the Northern Hemisphere is inclined away from the Sun, sunlight is spread over a larger surface area and people in the Northern Hemisphere experience winter. The seasons do not depend on how close Earth is to the Sun.

**Accommodation** By helping children learn how to ask good scientific questions and seek explanations based on sound evidence, and by teaching students to identify problems and seek solutions you will provide young people with the tools and rationale...
Alternative Learning Styles

Think about what’s the best way for you to learn. Is it enough to read the material and perhaps highlight key points here and there? Do you take notes as well? Or does your best learning come from discussing ideas with others or from doing a project or an activity? And what about the person sitting next to you in a class? Does he or she learn in the same way that you do?

Constructivism is based on the idea that we are unique as a result of our different life experiences and that these experiences result in our individual knowledge and beliefs. It is these differences in knowledge and beliefs that make us different from one another. And because we are all fundamentally different in this sense, we all learn differently, too. We have individual learning styles. And for you, as a science teacher, the implications of this are enormous.

One of your greatest challenges will be creating a classroom atmosphere and learning experiences that optimize learning for children with a diversity of learning abilities. It is not unusual for classrooms to have students with emotional, physical, and cognitive disabilities, gifted talents, or English language barriers. Differentiated learning and Universal Design for Learning (UDL) provide important teaching strategies that address the range of learning styles often encountered in a classroom.

Differentiated instruction acknowledges that all children do not learn alike and that instruction should provide several options for learning. Teachers need to create flexible yet focused learning experiences that recognize the diversity of learning approaches.

As you begin a unit on light, place an apple on the table and ask the children to write down whether they think that they would still be able to see the apple if the room were completely dark (with no light present at all) and to explain their answer. After reading some of the answers, you realize that some children believe that they could see the apple because the light goes from their eyes to the apple. Explain how the children might use assimilation, accommodation, or a combination of both to change this mental model.

for changing their mental models and deepening their understanding based not on whims, but on sound critical thinking. The NGSS recognize and support learning progressions that begin in elementary school but are reinforced and developed throughout their K–12+ career.

Children’s lives and future success will be greatly enhanced if they learn to appreciate the importance of stating hypotheses, gathering information systematically, and withholding conclusions until all the facts are in. If you emphasize the nature of careful scientific inquiry and the practices that support inquiry, then children will construct new and more complete understandings about the world in which they live.
Figure 2.3 Learning Styles for Your Science Classroom: Practical Applications

Learning Styles for Your Science Classroom

1. **It is likely that children prefer to learn in different ways.**
   
   **EXAMPLE**
   
   Study curriculum materials to ascertain whether they will accommodate differences in learning styles, and then develop some alternative teaching techniques. For example, if children are expected to name and describe the functions of the organs of the digestive system, study the unit carefully and try to come up with two or three different ways for children to learn this information.

2. **You can tell a great deal about how children learn by observing how they deal with new learning experiences.**
   
   **EXAMPLE**
   
   Early in the year, provide activities that include studying a section in a reference book, doing hands-on activities, doing library research, and working with a computer program. Observe how various children approach each task and their relative success with each.

3. **Provide a range of experiences in the classroom so that all children have opportunities to put their preferred learning styles to use as often as possible.**
   
   **EXAMPLE**
   
   Think about the extent to which the activities for each unit are the same or different in terms of what children actually do, and consider how you could build in variations in approach. For example, suppose you realize that all the activities for a unit on sound require the children to do the activity first, observe phenomena, and then report results. To accommodate children who have trouble with this approach, adapt a few of the activities early in the unit, so that children have the option of reading and talking about a concept before beginning an activity.

4. **Familiarize yourself with the needs of your students.**
   
   **EXAMPLE**
   
   Review Individualized Education Plans and speak with guidance counselors or previous teachers. Are there students in your class for whom English is a second language? Do any of the students have physical disabilities such as hearing or visual impairments? Are there children with learning disabilities among your students?

5. **Study the curriculum materials to ascertain whether they will accommodate a variety of learning options. Look for ways that you can incorporate multiple means of representation, expression, and engagement.**
   
   **EXAMPLE**
   
   As an engagement exercise, you plan to have students distinguish the sounds of mystery objects in a drop box, but this will be difficult for the hearing impaired students. Therefore, you could place the drop box on an improvised drum made out of a box with a balloon stretched across the top. All students can put their fingertips on the drumhead and feel the vibrations of different objects when they are dropped. This tactile experience not only benefits the hearing impaired students but also introduces all students to the role of vibrations in sound and sets the foundation for inquiries about frequency and pitch.
Project 2061 addresses the thinking skills you may wish to consider as you teach children science. Namely, they are outlined in the benchmark "Habits of mind":

- Values and attitudes
- Computation and estimation
- Manipulation and observation
- Communication skills
- Critical-response skills

Note that the item "Critical-response skills" is intended to help children separate sense from nonsense, which is crucial to helping them become scientifically literate citizens.

You'll find specific benchmarks (or recommendations) for the skills of most interest to you at the Project 2061 website: www.project2061.org.

UDL is an approach to teaching that facilitates differentiated instruction. It is similar in its approach to universal design in architecture by integrating structures everyone can use. Curb cuts and ramps that benefit wheelchair users are equally accessible by ambulatory people. Likewise, graphic organizers, visual displays, and vocabulary lists benefit all students, not just those with reading challenges. UDL is based on the following three general strategies:

- **Multiple means of representation**: provide learners various ways of acquiring information and knowledge
- **Multiple means of expression**: provide learners alternatives for demonstrating what they know and learn
- **Multiple means of engagement**: pique learners' interests, challenge them appropriately, and motivate them to learn

Differentiated learning and UDL play an integral role in lesson plans and strategies developed in Chapter 9.

Whether you are an experienced or new teacher, you have likely learned about learning styles. This is an interesting area of study because a variety of approaches are used to describe learning styles. Some expound about convergent and divergent thinkers; some emphasize the idea that some people prefer concrete experiences and others prefer abstract discussions of ideas and principles; some suggest that people can be grouped on the basis of whether they respond quickly (impulsive) or think first and talk or act later (reflective). See Figure 2.3 for some practical ways to acknowledge learning styles in your classroom.

**Summary**

2.1 Understanding How Children Learn Science

Growing knowledge of how children learn science suggests diversity among learners and greater potential for children to begin thinking scientifically at the elementary level than previously thought. Children learn science by doing science and reflecting on their actions. Teaching science effectively to elementary children requires a vision of the progression of learning.

2.2 Constructivism: A Modern View of How Children Learn Science

Constructivism, a useful theory about how children learn, has evolved from classical learning theories such as behaviorism and cognitive science. Constructivism
recognizes that individuals enter a learning situation with prior knowledge and that individuals modify or change their view of the world (mental models) through assimilation and/or accommodation. Learning is the acquisition of usable knowledge that can be recognized and applied (transferred) in a novel context. The challenge for you as a teacher is to help children replace naive conceptions or lack of knowledge about the natural world by constructing more accurate and complete understandings.

2.3 Ways to Support Your Constructivist Teaching

Science standards will help you identify the science content and practices that your children should be learning. Teaching strategies that support constructivist learning will be addressed in later chapters.

2.4 Alternative Learning Styles

Additional interesting insights about teaching and learning come from the knowledge that each of us has preferred styles of learning. Children come to our classrooms with a wide range of abilities. The more options available for learning experiences that challenge and deepen mental models, the more likely children will encounter rich learning experiences that connect with their learning styles. Differentiated instruction and Universal Design for Learning are two approaches that help us optimize learning for children with a diversity of learning styles.

On Your Own

1. Informally assess the extent to which you can apply your knowledge of the NGSS, UDL, and learning styles to support constructivist teaching in an actual science classroom. Do this by interviewing a primary-, elementary-, or middle-grade teacher to determine what factors he or she believes affect how well a child learns science and what types of science experiences happen in the classroom. Gather as much information as you can without guiding the interview toward any of the ideas from this chapter. After the interview, make a list that summarizes the key points made by the teacher. Categorize the items with respect to their relevance to constructivism, the standards, and learning styles. (Be mindful of preserving the confidentiality of your interviewee in any summary report you prepare.)

2. Interview a school principal to determine what he or she believes are the key factors that affect the quality of science instruction in the school. After the interview, prepare a chart that relates key phrases from the interview to the major ideas of this chapter.

3. Based on your personal experiences as a student in science classrooms, would you say that you have a preferred style of learning that leads to success in such environments? If you would, identify the factors that contribute to your preference.

On Your Own or in a Cooperative Learning Group

4. Have each member of the group interview at least one child to find out about his or her knowledge or beliefs about a key concept from the life, Earth/space, or physical sciences and technology. In the course of each interview, be sure to encourage the child to respond to questions that might reveal some naive conceptions. Use questions such as these: Why doesn’t the Moon fall to Earth? Are whales fish? Does the Sun move across the sky? Is a sweater warm?
5. As a group, reflect on the difference between assimilation and accommodation. Have group members identify one or two naive conceptions that they once had about the life, Earth/space, or physical sciences and technology. Have individuals indicate whether it was difficult or easy for them to revise these conceptions when they learned facts to the contrary or had direct experiences that produced results in conflict with their conceptions. Based on this group work, prepare a list of implications for teachers who wish to create science classroom environments in which children have experiences that reveal naive conceptions and lead to new learning.

**Print Resources**

**Suggested Readings**


Flores, M. M. “Universal Design in Elementary and Middle School.” *Childhood Education* 84, no. 4 (Summer 2008).


*Science Scope* 26, no. 4 (January 2003). (Entire issue emphasizes how to address misconceptions about science.)


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**Resources for Discovery Learning**

**Internet Resources**

- **Next Generation Science Standards:**
  www.nextgenscience.org
Notes