Instructional Sequence Matters

Grades 3–5

Patrick Brown

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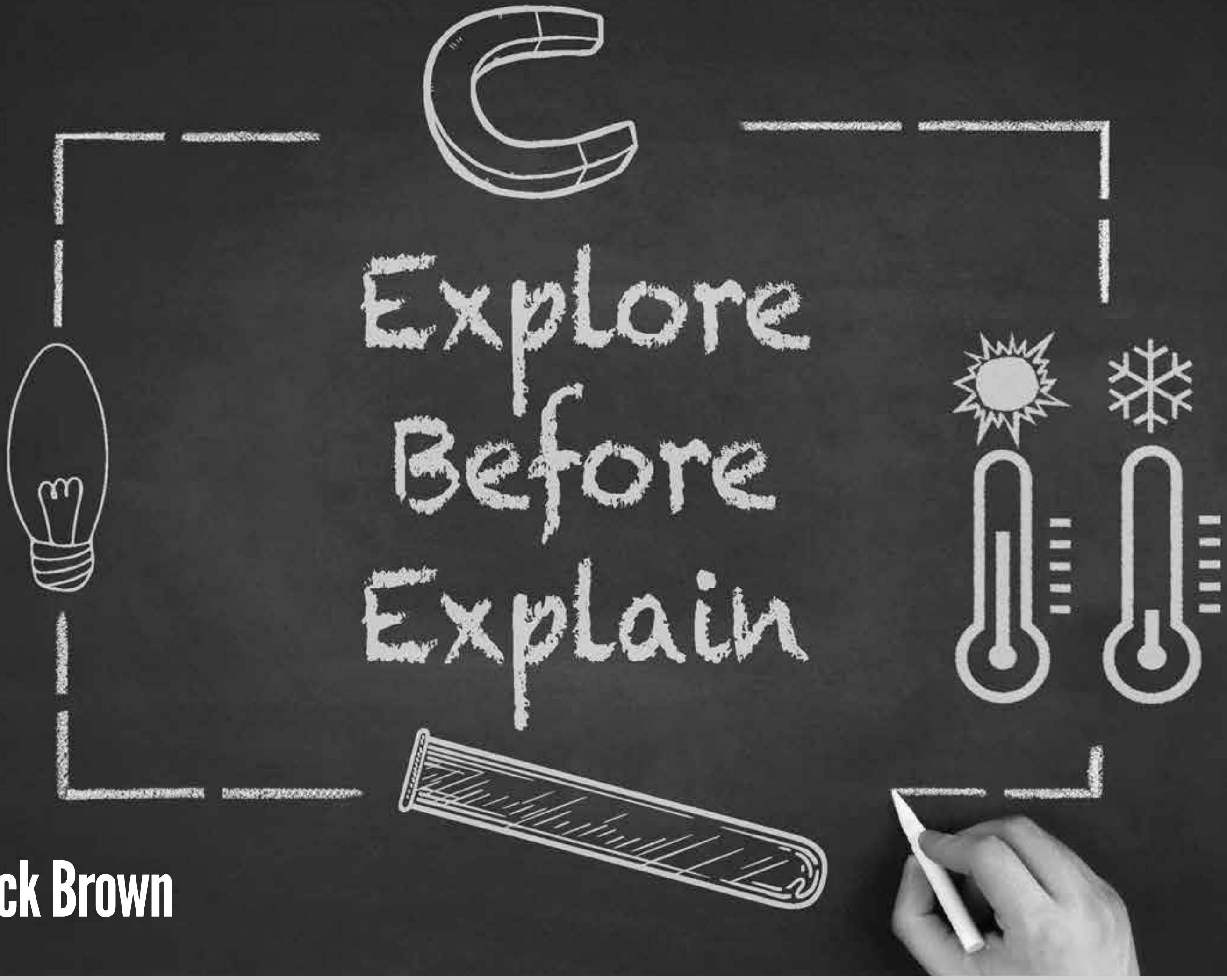

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To my favorite kid scientists: Finn, Lua, Bella, Charlie, Harry, Etta Mae, Penelope, Juliette, and Darby.

The more you read, the more things you will know.
The more things that you learn, the more places you will go.

—Dr. Seuss, *I Can Read With My Eyes Shut!* (Random House, 1978)

Contents

Foreword

From time to time, one identifies a new leader, someone the community has not recognized—yet. Then one goes to an NSTA conference and hears a presentation, joins a webinar, or reads an original book and realizes the leadership that is evident. This happened as I read *Instructional Sequence Matters, Grades 3–5: Explore Before Explain*.

Patrick Brown provides a wonderful book for science teachers. Not only is *Instructional Sequence Matters* a delightful read, it also is practical and helpful. What more could science teachers ask for? After starting with chapters on students' development and learning, modern sequences of instruction (including the 5E Instructional Model), and the synthesis of science concepts and practices, Dr. Brown describes various instructional strategies, such as demonstrations, readings, investigations, videos, and lectures, all components of integrated instructional sequences. The bulk of the book illustrates what it means to effectively teach science concepts such as heat and temperature, magnetism, and electric circuits.

Through the narrative and examples, Dr. Brown encourages teachers to change their mind-set about their instructional sequence. Using terms from the 5E Instructional Model (Bybee 2015), Dr. Brown demonstrates what it means to think about and apply *explore-before-explain* as a mind-set for teaching. Why did he embrace this mind-set? In his career, Dr. Brown observed and subsequently conducted research on preservice science teachers who had difficulty embracing the 5E Instructional Model because it was very different from their experiences and subsequent images of teachers and teaching and their successes as science students.

The rationale for using *explore-before-explain* as a mind-set also recognizes the importance of students constructing claims based on evidence before teachers provide explanations of science phenomena.

Finally, the examples help the reader address the dimensions of science and engineering practices, crosscutting concepts, and disciplinary core ideas as presented in the *Next Generation Science Standards* (*NGSS*) and many contemporary state science standards. Each example of an instructional sequence has clear connections to the *NGSS* and the *Common Core State Standards*.

In the final chapter, "Leadership and Lessons Learned," Dr. Brown lists lessons for teachers—for example, focus on science phenomena, emphasize *explore-before-explain* teaching, plan 5E (Engage, Explore, Explain, Elaborate, Evaluate) and POE (Predict, Observe, and Explain) lessons that incorporate *NGSS* domains, and recognize that changing one's mind-set about teaching takes time and conscious effort.

Foreword

I was originally drawn to this book because of Dr. Brown's use of the 5E Instructional Model. Reading *Instructional Sequence Matters* reinforced my first engagement with the book. Soon, however, I found other compelling reasons to recommend this book to all science teachers. The book is written by a teacher for teachers, it provides model lessons with a personal narrative that includes the decisions Dr. Brown himself had to make as a teacher, and it weaves in connections from the three dimensions of the *NGSS*. Finally, the book uses the 5E Model and presents descriptions of the model with insightful examples. Without any hesitation, I recommend this book.

—Rodger W. Bybee
Author of *The BSCS 5E Instructional Model: Creating Teachable Moments* (NSTA Press, 2015)

About the Author

Dr. Patrick L. Brown is the executive director of STEM and career education for the Fort Zumwalt School District in St. Charles, Missouri. Before arriving at Fort Zumwalt, he received a PhD in curriculum and instruction from the University of Missouri, Columbia.

Dr. Brown has a range of K–12 and postsecondary teaching experience. He has taught elementary-level, middle-level, and high school lessons. In addition, he has taught both undergraduate and graduate courses for prospective elementary, middle, and high school teachers. Dr. Brown has won various awards for his science methods course teaching.

Dr. Brown makes frequent presentations at international, regional, and state conferences and is known for his scholarship on instructional sequences to teach science. His science teaching ideas have appeared in *Science and Children*, *Science Scope*, *The Science Teacher*, and *Science Activities*. His research in science education has been published in *Science Education*, the *Journal of Science Teacher Education*, and the *International Journal of Science Education.*

Preface

Instructional Sequence Matters, Grades 3–5 is intended for elementary school educators, both new and experienced, as well as subject matter specialists, curriculum coordinators, and preservice and inservice trainers interested in enhancing student learning and motivation through simple shifts in their instructional practices. I provide numerous examples throughout the book about why instructional sequence matters from a pedagogical perspective and include many model lessons tied to contemporary national standards.

This book is intended to be the companion to *Instructional Sequence Matters, Grades 6–8*. I provide elementary teachers with a good balance between the theoretical foundations of effective teaching and learning and practical, classroom-tested instructional activities. As you will learn, *Instructional Sequence Matters* is all about *explore-before-explain* teaching, which is not a prescribed program but a way of thinking more purposefully and carefully about the nature of how we design instruction. While there are many changes and additions in this elementary-level version of the book, its philosophy and structure stay the same as the middle-level book. I wanted to keep some of the core examples and strategies that have stood the test of time and that I have used with elementary students. I had good reasons for keeping the model lessons the same as in the middle-level book: First, they were favorites among elementary students. And second, they all lead to students developing long-lasting understanding.

This book builds on *Instructional Sequence Matters, Grades 6–8* to meet some of the unique needs of elementary educators. I continue to suggest ways to advance students' science thinking in this book, grounded in the scholarship of teaching and learning. I include a mostly new chapter devoted to research on young children through adolescents. Many emerging bodies of research emphasize the importance of *explore-before-explain* teaching and expand on what we know about how people learn.

This companion book continues to illustrate the seamless translation of *explore-before-explain* teaching and the three dimensions of the *Next Generation Science Standards* (NGSS Lead States 2013): (1) science and engineering practices, (2) disciplinary core ideas, and (3) crosscutting concepts. These standards are described and closely connected to every aspect of the model lessons illustrating key physical science topics.

Finally, elementary teachers have to be picky about what they choose to read and how they teach, because they often work in a crowded school day where every instructional minute counts. I would challenge you to consider that *explore-before-explain* teaching can be so much more than a science lesson planning tool, and it lends empirical support for the placement of other experiences in the elementary classroom to leverage the best possible learning experiences for students. As you will learn, one of the hallmarks of *explore-before-explain* teaching is its emphasis on learning for understanding and wiring (or rewiring) the brain, so knowledge is deeply blanketed in evidence-based experiences. You will learn that using *explore-before-explain* teaching is an investment in student learning that can pay off big dividends. Teachers can use the context that science creates, and the brain-friendly development promoted by *explore-before-explain* teaching, to take students' interdisciplinary learning to higher levels. These assertions are supported by cognitive science research that emphasizes the critical importance of students' prior knowledge and how it is organized and expanded through cumulative learning experiences (Bransford, Brown, and Cocking 2000).

I have been gratified over the years by the number of positive responses I have received from elementary teachers and how their use of *explore-before-explain* practices with students has taken all learning to new levels. Even more rewarding than teacher compliments are the shared classroom memories from former elementary students who, as high school students and beyond, remember their *explore-before-explain* experiences in learning science.

Introduction

If I have seen further, it is by standing on the shoulders of giants.
—Isaac Newton (1675)

Students come to us as knowers. They have lived a few years and have constructed ideas about how the world works. They are puzzled when rainbows appear in the sky, when the leaves change colors, and when the Moon goes through different phases. Their observations can lead to questions about how the world works. Ever curious about their world, children instinctively try to answer their scientifically oriented questions by looking for patterns and causal relationships.

When they learn about the world, children do not just hit the right answers all at once. They develop ideas by building on previous experiences. There is a continuous advancement of thoughts, ideas, and sense-making. They correct errors in their thinking and revise misconceptions based on experiences. Their learning is not just dependent on the knowledge they construct entirely through self-discoveries. They receive explanations to help them understand the world. I firmly believe that a significant task of science teaching is cultivating the innate skills that child scientists bring to school and balancing their ideas with purposeful pedagogical practices. Bringing an *explore-before-explain* mind-set to science teaching is a way to develop the budding scientist in each of your students.

An *explore-before-explain* mind-set honors that students naturally develop ideas all on their own while it also highlights our essential role in their development. The framework is not a prescribed method, nor an advertisement for an entirely discovery-based approach to learning. It would not be necessary for students to rediscover all knowledge, which in many cases took scientists hundreds of years to invent. (This is applying the "standing on the shoulders of giants" idea to our important role as *explore-before-explain* teachers!) *Explore-before-explain* learning highlights a unique synergy between explorations and explanations, and it recognizes that explorations need to come first. Students' ideas and skills are powerful forces that drive intellectual development. Equally fundamental is how we provide explanations in light of students' life experiences. All learning is cumulative, and individuals' experiences as knowers—along with their interactions with teachers (and other adults, of course)—pave the way for developing a more sophisticated understanding. ("If I have seen further" is an implication of an *explore-before-explain* mind-set in the type of classroom culture of learning that we want to create for our students.)

Two contemporary ways to put an *explore-before-explain* mind-set into practice are the favored POE (Predict, Observe, and Explain) and BSCS 5E (Engage, Explore, Explain, Elaborate, Evaluate) instructional models. The POE and 5E instructional models sequence science instruction, so students explore science before elaborating their understanding from explanations. Both came from the three-phase 1960s science learning cycle (Atkin and Karplus 1962; Bybee 1997). In addition, the POE and 5E models allow students to construct content knowledge using science practices, a productive approach that mirrors how science is done in the real world. Later chapters will cover the similarities and differences among the learning cycle, POE, and 5E. These approaches are not a curriculum but a way to sequence activities so they align with how students learn best. If you are already aware of the power of the POE and 5E instructional models, this book may help you reflect on ways to make instruction even more effective for students. However, I hope it will do more than that. Others have written about using the 5E and POE models in teaching (see Abell and Volkmann 2006; Haysom and Bowen 2010). My approach is consistent with their ideas, but at the same time, it is unique.

A New Mind-Set for Approaching Science Teaching

We are all designers by nature, but how we strategize our planning practices can significantly facilitate the change we want to see in our lessons. As we embark on our journey, we will distinguish between *explore-before-explain* and 5E or POE teaching, because once we develop this mind-set, it drastically influences how we think about instructional design. While the details are soon to come, *explore-before-explain* teaching is all about creating conceptual coherence for learners. If we can begin our planning by thinking about the experiences students could have that would allow them to construct some accurate science knowledge, we can more easily situate learning around phenomena, decide explanations necessary for students as the science storyline unfolds, and offer elaborations to sophisticate student understanding.

I also highlight *explore-before-explain* teaching because it is not a predominating practice. A look into typical classrooms shows that hands-on activities have a standard script in U.S. classrooms where teacher explanation comes first, followed by verification and practice-type activities (Hofstein and Lunetta 2004). This type of approach fails to promote the kind of logical and critical thinking about data that can be used as evidence to explain science. In addition, this sequence does little to help students overcome inaccurate ideas and misconceptions that may be grounded in what could seem reasonable, but are unsubstantiated by empirical evidence and not an accurate depiction of science (Duschl, Schweingruber, and Shouse 2007). To help students develop knowledge by doing science, the National Research Council (NRC 2012) has suggested that they need to learn core ideas in different science disciplines (physical science, Earth and space science, and life science); be able to use the seven crosscutting concepts to think logically about data, evidence, and phenomena; and participate in eight science and engineering practices that allow for the construction of more accurate science knowledge.

While we will delve into the particulars of these essential practices, crosscutting concepts, and disciplinary ideas in later chapters, the motive for the change is threefold. First, as you will come to learn, students have a lot of room to grow. Second, students need to be the ones doing the hard intellectual work in the classroom to be prepared for the new trends, challenges, and skills necessary for global competitiveness in a changing workforce landscape. Finally, we need some new ways of thinking about teaching, to prepare students for their ever-changing world.

So why the change, and why now? Underlying the answer to this question are national and international assessments that seem to indicate that our students are not gaining proficiencies in science. These tests attempt to quantify students' preparedness for future schooling and for life. The National Assessment of Educational Progress (NAEP) assesses what students know and what they can do in different subject areas. Only 21% of students demonstrate science proficiency on the NAEP by 12th grade (U.S. Department of Education 2015). The ACT recently developed metrics to project potential success in different college science programs. According to the ACT (2015), merely 38% of students met or surpassed the science benchmark.

Students' potential to do better is similar to international tests. The Programme for International Student Assessment (PISA) measures students' abilities to think critically and solve problems in math, science, and reading. Results of the PISA test (from 2000, 2003, 2006, 2009, and 2012) demonstrate that U.S. students rank from 34% to 55% against students from other countries assessed in science (Organisation for Economic Co-operation and Development 2012). Meanwhile, the Trends in International Mathematics and Science Study (TIMSS) evaluates students' science and mathematics achievement. The latest TIMSS findings indicate that fourth- and eighth-grade U.S. students were ranked 11th and 12th, respectively, of all countries tested (International Association for the Evaluation of Educational Achievement 2015).

My point here is not to provide an exhaustive list of statistics on how our students perform, but to suggest that our lackluster results show a continuing shortfall in students' preparedness. Whether the assessment is looking at students' abilities to answer specific content questions or evaluating their logical thinking and reasoning abilities, we still have a long way to go. The results of national and international tests, as well as the outcomes of misconception research, indicate that we need a new way to think about teaching and learning. Now is the time to ask yourself, are you up for the challenge?

A General Overview for Using This Book

This book provides a self-guided professional development experience (see the Activity Box, pp. xx–xxi). The activities that follow will help you with national reform aimed at putting *A Framework for K–12 Science Education* (NRC 2012) and the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013) into practice.

Activity Box: Promoting Professional Development and Professional Learning Communities

The activity boxes throughout this book are meant to provide a professional development experience and promote job-embedded learning. Part of my hope is that your learning is ongoing and extends beyond the knowledge gleaned from reading this book and that you will try the model lessons and use the design practices to create your own *explore-before-explain* experiences. As with your students who benefit from *explore-before-explain* teaching, you will find that many of the lessons require learning by doing. One difference is that I have structured the book so an explanation of learning theory and instructional sequence is up-front. You might try to do a model lesson first, before diving deep into the research sections that start with Chapter 1. (This would be an *explore-before-explain* approach to your professional development!)

We can increase our learning by collectively working together. A professional learning community (PLC) is dedicated to working collaboratively to improve learning for students. If we use PLCs to collaborate, we need to establish some parameters for our work:

- *What are the expectations of the group?*
  Representative activities: How will the team decide on group norms? Will the team be establishing group member roles?
- *What are the expectations for student learning? What sources will be drawn on when we decide on our expectations for learning?* Representative activities: How will science standards drive our expectations for student learning? Can we use science as a vehicle for developing a student's proficiency in the ***Common Core State Standards***? If so, what standards will we draw on to reinforce our work?
- *What results will we focus on to determine whether our approaches are leading to higher levels of learning and motivation?*
  Representative activities: Can we use common pretests and posttests to assess students' development of understanding? What performance tasks might help us know whether students have

gained the necessary proficiencies in science content and practices? Can students track their science content and practices development (i.e., can we promote a metacognitive approach)?

- *How will we measure the effectiveness of our PLC?*
  Representative activities: Can we measure our adherence to *explore-before-explain* teaching by looking at similarities and differences between our past and current lessons? Can we offer lessons studies where we observe each other's *explore-before-explain* lessons?

My goal is that teachers will read the chapters, reflect on their practices, learn from the examples, and use the design principles to start creating 5E and POE lessons that align with the *NGSS*. This book draws heavily from the research on effective professional development that highlights the critical role of active learning in context and explicit reflection in practice (Reiser 2013). Also, research from *The Cambridge Handbook of Expertise and Expert Performance* recognized that developing knowledge is most meaningful if it is integrated into practice (Ericsson et al. 2006). Thus, to become experts, teachers will need time to think about the sequence of science instruction and the *NGSS*, and they probably will not be perfect right at the start.

Each chapter of this book grew out of research experiences, from working with elementary students, and through teacher preparation and professional development. I have embedded activities aimed at sparking your thinking about your own experiences and designing *explore-before-explain* instructional sequences (see the activity boxes throughout the chapters). I learned through research that teachers can have difficulty embracing the 5E Instructional Model because this instructional sequence is different from their experiences as students and their mind-set toward science teaching (see Brown, Friedrichsen, and Abell 2013). Success in K–16 science experiences can provide robust ideas about what science teaching could look like and how to best prepare students to develop their understanding.

You can use the discussion questions in this book to reflect on, both individually and with colleagues, your beliefs about science teaching and experiences as a learner. Our experiences as learners, current work with students, and beliefs about effective instruction can be compelling evidence for our ideas and inform our future practices. During the reading activities, make note of ideas so you can easily reflect on their initial discussions after experiencing model lessons. The combination of reflection questions, research chapters, and model lessons strongly supports an *explore-before-explain* mind-set.

In Chapter 1, "Rethinking Development and Learning," I start with the research on learning and cognition. This chapter takes you through some of the emerging ideas about students' intellectual abilities in terms of developmental psychology, neuroscience, and cognitive science research and the implications for the instructional sequence.

Chapter 2, "Connecting Hands-On With Minds-On Experiences," shows why the exact placement of activities in instruction is pivotal in learning. I compare two different hands-on approaches. I support the assertions about why *explore-before-explain* teaching is beneficial for learners with abundant science education research that can be further explored.

Chapter 3, "Modern Sequences of Instruction," discusses the key components of two contemporary sequences of science instruction. You will read about the phases of the POE and 5E instructional models. The activity boxes are aimed at helping you reflect on hands-on practices you currently use and how they may be sequenced to promote even higher levels of learning.

In Chapter 4, "Content and Process Working Together," I describe the construction of the *NGSS*. I share some activities for you to reflect on the lessons you currently use and the connections to components of the *NGSS*.

Next, in Chapter 5, "Where to Start," I provide guidance on how you can create 5Es that translate the *NGSS*. I present activities following each factor that you should consider when planning 5Es and offer some planning ideas to design *explore-before-explain* instructional sequences based on cognitive science research.

In Chapters 6–13, I share grades 3–5 model lessons for putting the *explore-before-explain* mind-set into practice using either a POE or a 5E instructional sequence in physical science, life science, and Earth and space science. I offer the lessons from the different disciplines from a grade-span perspective because how you cluster standards to make learning meaningful for students is vital. As you will come to see, the *explore-before-explain* activities create the science storyline and the gradual unfolding of related ideas. Occasionally, standards across the grade span are touched on or addressed at an earlier grade than recommended by the *NGSS* to build students' conceptual coherence. The model lessons illustrate how both the POE and 5E models easily translate into the *NGSS*. Also, the narrative portions of the model lessons are coded with specific elements of the *NGSS* (NGSS Lead States 2013, Appendixes F and G). An *NGSS* summary table is provided to show the close connection between student actions and *NGSS* dimensions. The model lessons allow you to see the POE or 5E model and the *NGSS* in action.

Chapter 14, "Leadership and Lessons Learned," takes you through five key points for putting an *explore-before-explain* mind-set into practice using POE and 5E sequences and the *NGSS*. This final chapter can help emphasize the steps necessary for supporting colleagues and developing collaborative teams interested in shepherding the POEs and 5Es into practice.

Conclusions

Teacher educators and professional developers can easily implement these lessons to model best practices in science education. Beginning teachers can use the model lessons so they have research-based strategies to improve student learning during their first years of teaching. Experienced teachers who already value hands-on approaches but find that their lessons fall slightly short in influencing students the way they intended can benefit from simple reorganizing activities. Reading and discussing the chapters provides valuable insight into why some approaches may be more beneficial than others. Thus, teachers have real-life examples and a rationale for restructuring the hands-on approaches they are currently using. Regardless of the level of experience, from novice to expert teacher, educators can read, implement, and dissect each model lesson to help reflect on how the sequence of science instruction promotes long-lasting understanding.

The chapters build on one another so you can consider why some activities may be even more effective than others and so you can try them out with your students. Many teachers realize that simple shifts in the arrangement and combination of activities can positively affect student learning. In addition, effective science teaching is not always about working harder—it is about working smarter. Reflecting on and experiencing exploration before explanation instructional sequences opens up opportunities to construct a theoretical model for classroom lesson design so that all students gain higher levels of science literacy.

A NOTE ON SAFETY

Science teaching necessarily involves working with different materials, and at times, this can pose safety hazards. Safety *always* needs to be the first concern in all of our teaching. Teachers need to be sure that their rooms and other spaces are appropriate for the activities being conducted. That means that engineering controls such as proper ventilation, a fire extinguisher, and an eye-wash station—and appropriate personal protective equipment (PPE) such as safety goggles or safety glasses with side shields and gloves—are available and used properly. In addition, there should be sanitized, indirectly vented chemical-splash goggles or safety glasses with side shields as appropriate, nonlatex aprons, and vinyl gloves during all components of investigations (i.e., the setup, hands-on investigation, and cleanup) when students are using potentially harmful supplies, equipment, or chemicals.

At a minimum, the eye protection PPE provided for students to use must meet the ANSI/ISEA Z87.1 D3 standard. Remember to review and comply with all safety policies and procedures, including appropriate chemical management, that have been established by your school district. Teachers must also practice the proper disposal of materials, even common items such as baking soda and vinegar, as well as the proper maintenance of all equipment.

Continued

Introduction

The National Science Teaching Association maintains an excellent website (*www.nsta.org/safety*) that provides guidance for teachers at all levels. The site also has a safety acknowledgment form (sometimes called a "safety contract") that is specifically for elementary students to review with their teachers and have signed by parents or guardians (see *http://static.nsta.org/pdfs/SafetyAcknowledgmentForm-ElementarySchool.pdf*).

It cannot be overstated that safety is the single most important part of any lesson. Safety notes are included throughout this book to highlight specific concerns that might be associated with a particular lesson.

The safety precautions associated with each investigation are based, in part, on the use of recommended materials and instructions, legal safety standards, and better professional safety practices. The selection of alternative materials or procedures for these investigations may jeopardize the level of safety and therefore is at the user's own risk. Remember that an investigation includes three parts: (1) the setup, which is what you do to prepare the materials for students to use; (2) the actual investigation, which involves students using the materials and equipment; and (3) the cleanup, which includes cleaning the materials and putting them away for later use. The safety procedures and PPE stipulated for each investigation apply to all three parts.

Chapter 12

A Natural Storyline for Learning About Ecosystems

Chapter 12

Activity Box: Exploring Storylines

Use the activities below to reflect on the model lesson in Chapter 12. Go back and forth between your reflection journal and the model lesson. You can use the activities individually or as a group to reflect on how the 5E (Engage, Explore, Explain, Elaborate, Evaluate) sequence of instruction influences student learning.

1. **Think about the model lessons presented so far and the life science and Earth and space science 5Es presented in this chapter's model lesson. Compare and contrast hands-on explorations for different disciplines (life science and Earth and space science vs. physical science). How are the hands-on explorations similar and different for different disciplines (e.g., physical vs. life vs. Earth and space science)?**
2. **Brainstorm a list of topics in one discipline that connect with other ideas in other disciplines. How can you bundle together ideas to help students see connections?**
3. **Think deeply about the models that you currently have students create and the ones in this chapter. Does your use of a scientific model allow students to explain and predict science ideas? What are the limitations of the scientific models that your students use to understand science?**

Children are fascinated by nature and come to class having ideas about plants, animals, and their environment. Students' ideas are based on their firsthand experiences. For example, many kids have pets, children's books are abundant with stories about wildlife, and television and children's cartoons often highlight the relationships between people and animals. Capturing students' attention about living things is not difficult; however, students' lived experiences alone do not provide them with comprehensive understandings of living things and their interactions and the basic requirements of life. In this regard, research shows that students have misconceptions about the characteristics used to determine whether something is living as well as about the underlying relationships and interactions of organisms in an environment (Driver et al. 1994).

A Natural Storyline for Learning About Ecosystems

What follows is a third-grade *explore-before-explain* lesson aimed at developing students' ideas about living things and Earth's systems. As you will see in this lesson, all students are ready to learn at high levels if the content is sequenced in ways where we tap into their prior knowledge and follow up with firsthand explorations that directly relate to their experiences. This lesson is a case in which students' prior experiences directly relate to standards at different grade levels and allow them to explore phenomena in different disciplines. Thus, the storyline includes life science and Earth and space science topics bundled together and begins to address the *Next Generation Science Standards* (*NGSS*) performance expectations (PEs). The PEs include students developing a model to describe the "movement of matter among plants, animals, decomposers, and the environment" (5-LS2-1) and "to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact" (5-ESS2-1; NGSS Lead States 2013).

Also, the activities help students work toward understanding the PE that states they should be able to "construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction" (4-LS1-1; NGSS Lead States 2013). The idea behind creating storylines for students is that disciplinary core ideas, science and engineering practices, crosscutting concepts, and PEs should be organized in ways to help students develop broader understandings. Rather than approaching learning as a siloed approach and specific to one topic or one discipline at one grade level, we can include ideas that build and support students' past experiences as well as future learning in all science areas to create more coherent frameworks for students trying to understand natural phenomena.

The model lessons include an illustrative example of how to use a formative prior knowledge assessment probe that translates into a firsthand exploration. Students' evidenced-based claims are supported by authoritative explanations using a book and a teacher description to promote more accurate science understanding. All three dimensions of the *NGSS* are easily addressed through the combination of hands-on, minds-on activities (see the table at the end of this chapter).

Assessing Students' Prior Experiences

Engage Phase, Day 1 (25 minutes)

I kicked off the lesson by using a formative prior knowledge assessment probe that was designed to home in on meaningful and relevant phenomena that would be the storyline for our unit exploring life and the interdependence of organisms. We wanted to think about what makes something living and how things are connected in our world in order to maintain life. I used a modified version of the formative assessment probe "Is It Living?" to determine students' experiences (Keeley, Eberle, and Farrin 2005). I purposely focused on ideas in our version of "Is It Living?" that could seamlessly translate into some of our firsthand investigations (see Figure 12.1, p. 120).

I learned from the formative assessment probe that students had different ideas about living versus nonliving and had an incomplete understanding of what factors make some things living versus not living. As my students discussed the reasons for

Chapter 12

Figure 12.1. *The Modified Version of "Is It Living?"*

Listed below are examples of living and nonliving things. Put an X next to the things that could be considered living.

Item Number	Item	Initial	Conversations
1	Tree		
2	Rock		
3	Fire	?	?
4	Wind	?	
5	Grass		
6	Seed		
7	Water	?	
8	Worm		
9	Sun	?	?
10	Snail		

Explain your thinking. What reasoning did you use to decide if something could be living?

Note: **?** = student unsure.

their thinking, they engaged in argumentative discourse where they used logic to try to persuade their peers about their ideas. My role during the conversation was to be a facilitator, and not a judge who evaluated the correctness of ideas and students' logic. I jotted words and notes on the board because the conversation was very fast-paced, and I occasionally asked probing questions to keep the conversation moving along a specific path. For instance, early in our discussion of what makes something living, a student said that "it needs water." I added *water* to the board. The students immediately bought into this idea and wanted to change their initial answers about the wind and water being living and mark them as nonliving.

Another student said that movement was a characteristic of living things. I added the term *movement* to the list. Movement was a tougher defining characteristic for students to use to justify their ideas. For instance, I asked the class, "Do all living things move?" A student said, "Well, plants are living and they don't like to move by themselves. A person can move them. Wind can move them."

The conversations so far about water and moving led directly to discussing fire and the Sun. The students were torn on whether fire and the Sun were living or nonliving based on our list. They went back and forth in their discussion.

Alan: *Fire doesn't need water.*

Janice: *I think it's living* [referring to fire]. *It kinda, like, can spread and move.*

Lisa: *Yeah, it looks like it is alive.*

Janice: *The Sun is living because it's like fire.*

Another student chimed in and changed the direction of the conversation. He said things that are living need food and explained, "Food for grasses would be fertilizer and stuff like that and the dirt. Snails like to eat algae off of plants."

To begin to focus the discussion, we looked at our list, which included water, motion, and food. Students wanted to know if their checklist of living and nonliving things, as well as their characteristics, was correct. I looked at both lists and asked the class, “Can any of the things we identified as living live completely on their own without anything else?” In unison the class said, “No.” I asked the same about the things that we thought were nonliving. Before the class could answer, a student said, “A rock is not living and doesn’t need anything.” At this point, we all agreed that all living things, at some level, need something else that is living (or once living) to survive. This basic idea would be the focus of our exploration.

SAFETY NOTES

1. Wear sanitized, indirectly vented chemical splash safety goggles or safety glasses with side shields and a nonlatex apron during the setup, hands-on, and take-down segments of the activity, for both students and teacher.
2. Use caution when working with sharp objects (e.g., glass or plastic). They can cut or puncture skin.
3. Have direct adult supervision when working on this activity.
4. Immediately wipe up any liquid spilled on the floor—a slip-and-fall hazard.
5. Wash your hands with soap and water after completing this activity.

Exploration

I wanted my students to have experiences with data and models to begin to explore the interdependence of living things. My goal was to test students’ ideas and have them explain the closed system in different ways over many days. In this way, I wanted the students to construct knowledge from their experiences, with my role being to introduce scientific terminology and vocabulary in light of their firsthand experiences. I chose to use a bottled ecosystem (designs are abundant on the internet, and there are entire curricula that use 2-liter bottles to model closed ecosystems). We used very simple materials to map out the connectedness among different components of the ecosystem, including snails, worms, aquatic plant bulbs, soil, water, and seeds (see Figure 12.2).

Figure 12.2. *Simple 2-Liter Bottle Ecosystem*

I wanted to include organisms that naturally live together while also being cognizant of the National Science Teaching Association’s minimum safety practices and regulations (bottled ecosystems should not include vertebrates) (Ingram 1993; see *http://static.nsta.org/pdfs/MinimumSafetyPracticesAndRegulations.pdf*). I provided the students with a list of organisms we would use, and we constructed the bottled ecosystem together. In addition, we purposely created natural habitats that interact, such as terrestrial and aquatic environments. (As a safety note, students' main role was to add the necessary components to the 2-liter system. They have difficulty cutting 2-liter bottles, so I performed this task for them. I took the lead on providing the students with the procedure for constructing the ecosystem.)

Day 2 (25 minutes)

Students eagerly hovered around our ecosystem looking for changes. I wanted to guide them in thinking about the system we were using in our explorations to highlight that scientific models explain, predict, and have limitations (NGSS Lead States 2013). I asked the students to focus their writing in their science notebooks, and to consider their observations and the ways the ecosystem is similar to and different from how these organisms exist in nature.

Figure 12.3. *Condensation Forming on the Bottle*

Figure 12.4. *Drop of Water Accumulating at the Tip of the Straw*

We noticed that one of the first changes was that condensation formed on the bottle and a drop of water accumulated at the tip of the straw (see Figures 12.3 and 12.4). The condensation and water droplets were key sources of evidence for students' construction of knowledge. The students explained that our bottled ecosystem was like nature and the "water is like rain because it goes through the straw and goes back in the water and makes a cycle."

A student also noticed a difference between real-life habitats and our bottled ecosystem. The bottled ecosystem had only a few organisms; as a student explained, "Worms don't live alone in the wild." Thus, the students were realizing that while helping us explain how organisms interact, the bottled ecosystem was a very simplified model of the real world.

Days 3–6 (10–15 minutes a day)

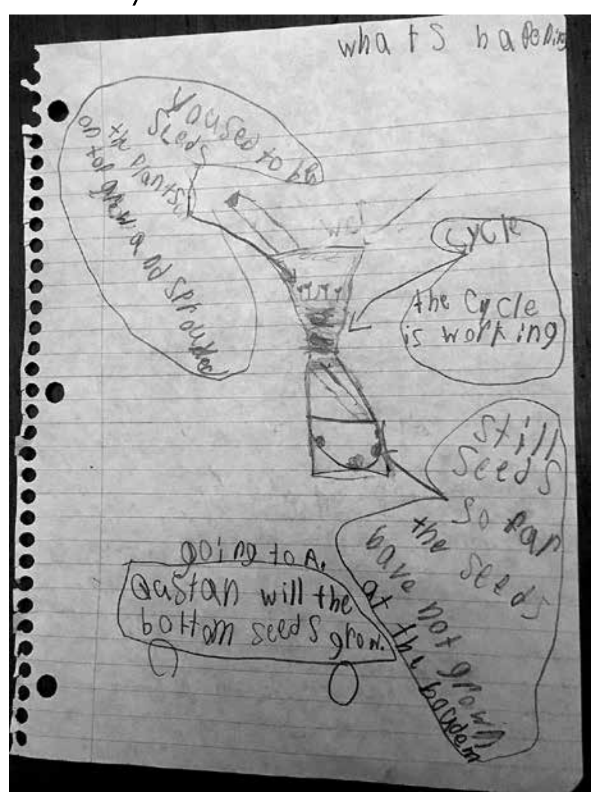
Using the students' science notebooks, we continued collecting data about our ecosystem over the next few days. The students drew pictures of the individual organisms and labeled their specialized parts (4-LS-1; NGSS Lead States 2013). For instance, a student drew a snail and identified that the mouth was specially designed for eating.

I also wanted to focus student thinking on the relationship between living and nonliving things in the ecosystem and to list the materials in both the terrestrial and aquatic habitats. The observation and data collection period reached a new level of enthusiasm when the flowering plants began to sprout (see Figure 12.5).

Figure 12.5. *Plants Begin Sprouting on Day 4*

At this point, I asked students to use arrows to describe how different components were connected. I was pleasantly surprised about what the students were learning about the ecosystem (see Figure 12.6). One student listed his ideas about the system as a whole and wrote "big cycle" and "connected." His list showed how different components of the ecosystem were linked. For instance, his arrows showed that the water plants are connected to the Sun and get water from their aquatic habitat and the snails get food from the water plants. He showed that a straw was used to connect the terrestrial and aquatic habitats and that the aquatic habitat was the water source for the terrestrial environment and the plants buried in the soil (5-ESS2-1; NGSS Lead States 2013).

Figure 12.6. *Student Identifying Connections Between Living and Nonliving Things in the 2-Liter Bottle Ecosystem*



The sprouting of plants was also a pivotal day for the students' construction of knowledge, and they could make an evidence-based claim about the interdependence of organisms (in other words, their ideas about a "big cycle" and "connected" were related to their observations). What the students did not know was the details of the specific nature of the connections and matter being cycled. We were ready for a more detailed description of how matter cycled through the ecosystems.

Authoritative Explanation (50 minutes)

The purpose of the Explain phase was to introduce new terms and ideas in light of students' firsthand experiences. We kicked off the explanation by reading excerpts from *There's a Hair in My Dirt! A Worm's Story* (Larson 1998). The book introduced a whole host of ideas related to our unit of study. Students learned that "plants did a little more than just make the air crisp and clean—they made the air! Every molecule of oxygen in the Earth's atmosphere was put there by a plant" (Larson 1998, p. 11). I supported the students' developing understanding by having them draw diagrams in their science notebooks with arrows showing that the oxygen produced by plants cycles to the animal life, and the carbon dioxide produced by animals cycles to the plant life. The students also gained a new appreciation for worms when we read the following:

> *Take us worms, for example. We till, aerate, and enrich the earth's soil, making it suitable for plants. No worms, no plants; and no plants, no so-called higher animals running around with their oh-so-precious backbones!* (Larson 1998, p. 52)

We talked about the interactions in the bottled ecosystem and what the students were learning from the reading, and we highlighted three key ideas emphasized by the *NGSS* (NGSS Lead States 2013): (1) Plants are a basic food source for other living organisms; (2) some animals eat plants, and others eat the animals that eat plants; and (3) microscopic bacteria decomposers break down dead organisms as a food source for macroscopic decomposers such as worms. In addition to the students gaining new invertebrate insights, the book validated their evidence-based claims about everything being connected in an ecosystem.

The second portion of the explanation also dealt with cycles, and we made connections between our aquatic and our terrestrial components to Earth's systems. This was a nice tie to Earth and space science. The students had evidence from their experiences that soil, air, and water environments all were necessary components. The students' future experiences would attach scientific terminology to their experiences; the *hydrosphere* helped support life for our plants and animals (*biosphere*), and the *atmosphere* brought water back as *precipitation* (5-ESS2-1; NGSS Lead States 2013). With a basic understanding in place, it was time to see if student understanding transferred to other circumstances.

Elaborate and Evaluate (25 minutes)

The Elaborate phase is dedicated to testing the idea that ecosystems contain organisms that are connected in meaningful ways to sustain life. I asked my students to draw pictures of grass, trees, bugs, birds, and hawks. Next, we cut out the pictures and used them to create and explain a food web. This extension activity asked students to consider a more complex food web (an animal that eats animals) than in our bottled ecosystem. I also asked the students what would happen if the bird were removed from their food web. They realized that the top portion of the food web would be affected if the bird were removed.

The evaluation activities were a chance for me to assess student understanding and for students to think about their developing understanding. The students' answers to the food web in the elaboration activity were my assessment of whether they had gained knowledge of the interdependence of organisms. As a student self-assessment, we went back to their initial ideas about living and nonliving things. The students decided that while the Sun is an essential factor and is integral for life, the Sun and fire are not living things.

While our hands-on experience did not allow students to construct knowledge of the Sun being living versus nonliving, the storyline that the lesson created helped situate the students' learning. Thus, the impact of direct instruction was a particularly potent learning experience and was situated in a broader conceptual framework of life science and Earth and space science. In this way, the students connected the initial assessment probe with their explorations and explanations, and they reflected on their developing understanding.

Conclusions

The most powerful and productive learning environments tap into students' innate abilities and allow them to construct some knowledge from firsthand experiences (National Academies of Sciences, Engineering, and Medicine 2018). While building bottled ecosystems is not a new activity, a way to heighten learning is in the sequence of the assessment probe leading seamlessly to an investigation where students can construct new knowledge. The uniqueness of this lesson is in the research-based instructional sequence that connects well with other topics within a grade level and builds knowledge for future learning. The end result is that students' learning is heightened because they use science practices to construct knowledge based on their firsthand experiences.

See Table 12.1 (p. 126) for the *NGSS* connections visited in this chapter.

Table 12.1. *Unwrapping the* Explore-Before-Explain *Ecosystem Lesson*

Ecosystems: Interactions, Energy, and Dynamics and Earth's Systems	**Connections to Classroom Activity**
Performance Expectations	
5-LS2-1: Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.	Students used 2-liter bottles to create a closed ecosystem that included two connected components: aquatic and terrestrial environments.
5-ESS2-1: Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.	
4-LS1-1: Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction.	
Science and Engineering Practices	
Asking questions and defining problems	Students' predictions about living and nonliving things led to investigative questions about how things interact in an environment.
Planning and carrying out investigations	Students helped build a 2-liter bottle ecosystem to explore how the living and nonliving interact in an ecosystem.
Developing and using models	Students labeled different parts of the 2-liter bottle ecosystem.
Constructing explanations	Students created diagrams to explain how different parts of an ecosystem are related.
Disciplinary Core Ideas	
LS2.A: Interdependent Relationships in Ecosystems: The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plants parts and animals) and therefore operate as "decomposers." Decomposition eventually recycles some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem.	Students' firsthand experiences with the bottled ecosystem were connected to what they learned through reading and a teacher explanation. The teacher explanation introduced food webs and decomposers.

Continued

Table 12.1. (*continued*)

Ecosystems: Interactions, Energy, and Dynamics and Earth's Systems	Connections to Classroom Activity
Disciplinary Core Ideas (*continued*)	
LS2.B: Cycles of Matter and Energy Transfer in Ecosystems: Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases, and water, from the environment and release waste matter (gas, liquid, or solid) back into the environment.	Students considered the relationship between plants and animals in the bottled ecosystem. They learned from the reading that plants produce oxygen. During the teacher explanation, they created diagrams showing the reciprocal exchange of gases between plants and animals (i.e., plants produce oxygen and animals produce carbon dioxide).
LS1.A: Structure and Function: Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction.	Students closely observed one living thing to describe specific features and their purposes.
ESS2.A: Earth Materials and Systems: Earth's major systems are the geosphere (solid and molten rock, soil, and sediments), the hydrosphere (water and ice), the atmosphere (air), and the biosphere (living things, including humans). These systems interact in multiple ways to affect Earth's surface materials and processes. The ocean supports a variety of ecosystems and organisms, shapes landforms, and influences climate. Winds and clouds in the atmosphere interact with the landforms to determine patterns of weather.	Students learned from their bottled ecosystem that the aquatic habitat provides water for the terrestrial habitat. Earth systems are similar to the 2-liter bottle ecosystem and interact and affect each other in multiple ways.
Crosscutting Concepts	
System and system models	Students used scientific models to explain the interactions that occurred within the bottled ecosystem and make predictions about other examples of ecosystems.
Cause and effect	Students predicted the influence of changing one factor on another in the bottled ecosystem.

Note: The materials, lessons, and activities outlined in this chapter are just one step toward reaching the performance expectations listed in this table. Additional supporting materials, lessons, and activities will be required. For more information, see *www.nextgenscience.org/pe/5-ls2-1-ecosystems-interactions-energy-and-dynamics, www.nextgenscience.org/pe/5-ess2-1-earths-systems,* and *www.nextgenscience.org/pe/4-ls1-1-molecules-organisms-structures-and-processes*.

Index

Page numbers printed in **boldface type** indicate tables or figures.

Index

Index

Index

Instructional Sequence Matters

Grades 3–5

Explore Before Explain

Instructional Sequence Matters, Grades 3–5 is a one-stop resource that will inspire you to reimagine how you teach science in elementary school. The book discusses two popular approaches for structuring your lessons: POE (Predict, Observe, and Explain) and 5E (Engage, Explore, Explain, Elaborate, and Evaluate). It also shows how simple shifts in the way you arrange and combine activities will help young students construct firsthand knowledge, while allowing you to put the ***Next Generation Science Standards*** (***NGSS***) into practice.

Like its popular counterpart for grades 6–8, the book is designed as a complete self-guided tour. It helps both novice teachers and classroom veterans to understand

- **Why sequence matters.** A concise review of developmental psychology, neurosciences, cognitive science, and science education research explains why the order in which you structure your lessons is so critical.
- **What you need to do.** An overview of important planning considerations covers becoming an "explore-before-explain" teacher and designing 5E and POE instructional models.
- **How to do it.** Ready-to-teach lessons use either a POE or 5E sequence to cover heat and temperature, magnetism, electric circuits, chemical changes, ecosystems, and Earth processes. Detailed examples show how specific aspects of all three dimensions of the ***NGSS*** can translate into your classroom.
- **What to do next.** Reflection questions will spark thinking throughout the sequencing process and help you develop the knowledge to adapt these concepts to your students' needs.

Instructional Sequence Matters will give you both the rationale and the real-life examples to restructure the hands-on approaches you are now using. The result will be a sequence for science instruction that promotes long-lasting understanding for your third-, fourth-, or fifth-grade students.

"I was originally drawn to this book because of Patrick Brown's use of the 5E Instructional Model. Soon, however, I found other compelling reasons to recommend it. The book is written by a teacher for teachers, it provides model lessons with a personal narrative about the decisions Dr. Brown himself had to make as a teacher, and it weaves in connections from the three dimensions of the ***NGSS***. Finally, it uses the 5E Model with insightful examples. Without any hesitation, I recommend this book."

—Rodger W. Bybee, author of ***The BSCS 5E Instructional Model: Creating Teachable Moments*** (NSTA Press, 2015)

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