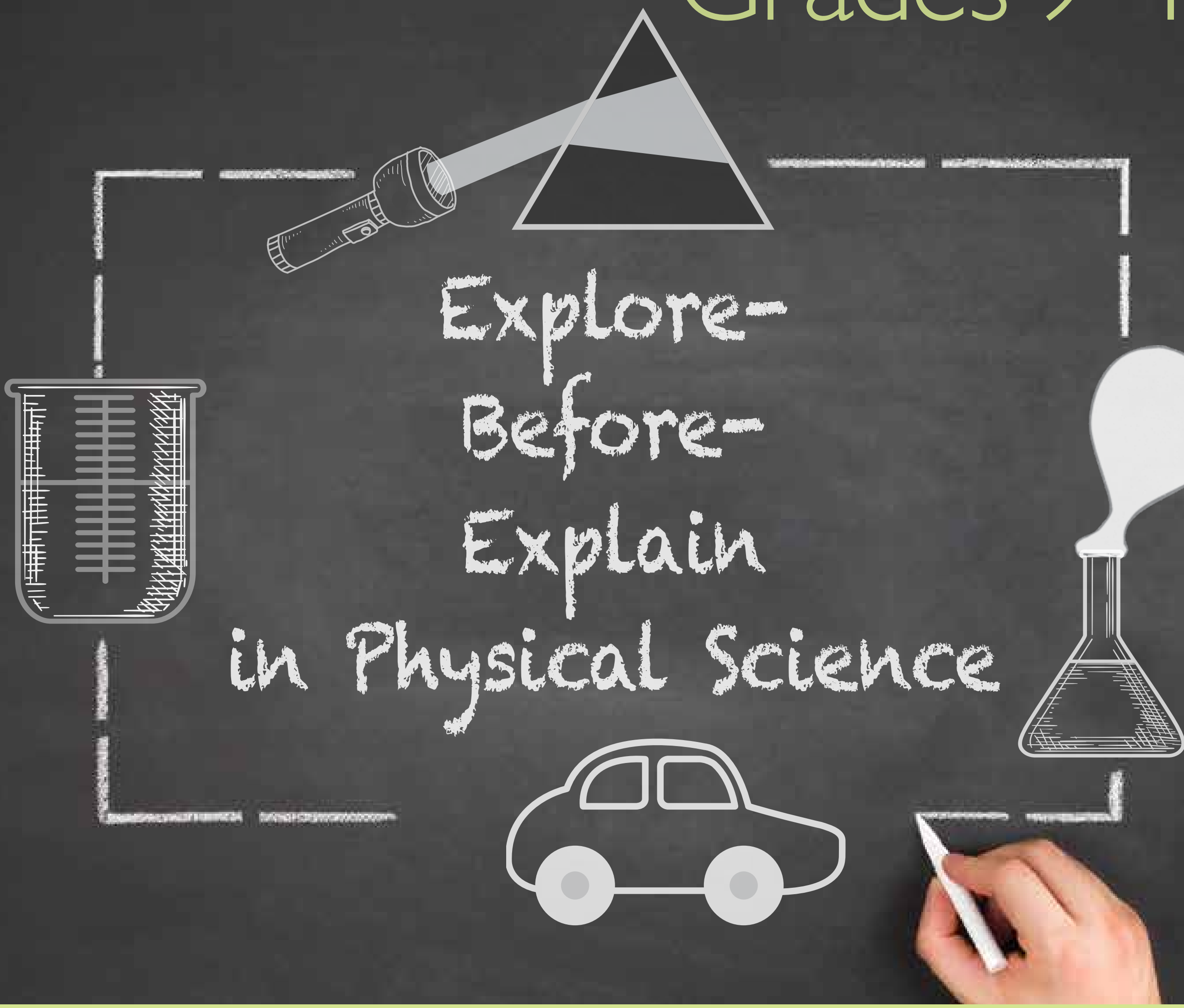
Instructional Sequence Matters

Grades 9–12



Explore-Before-Explain in Physical Science

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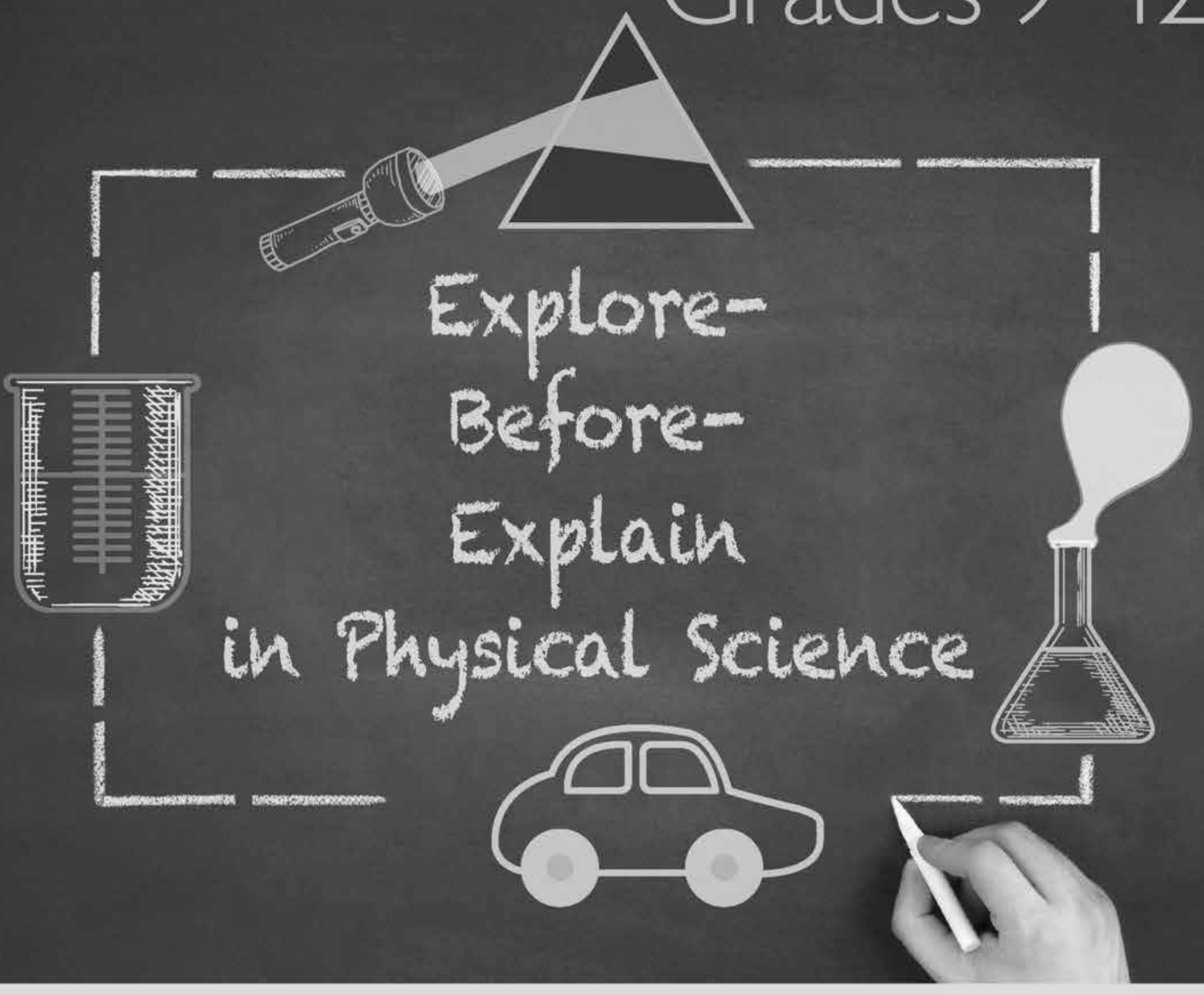

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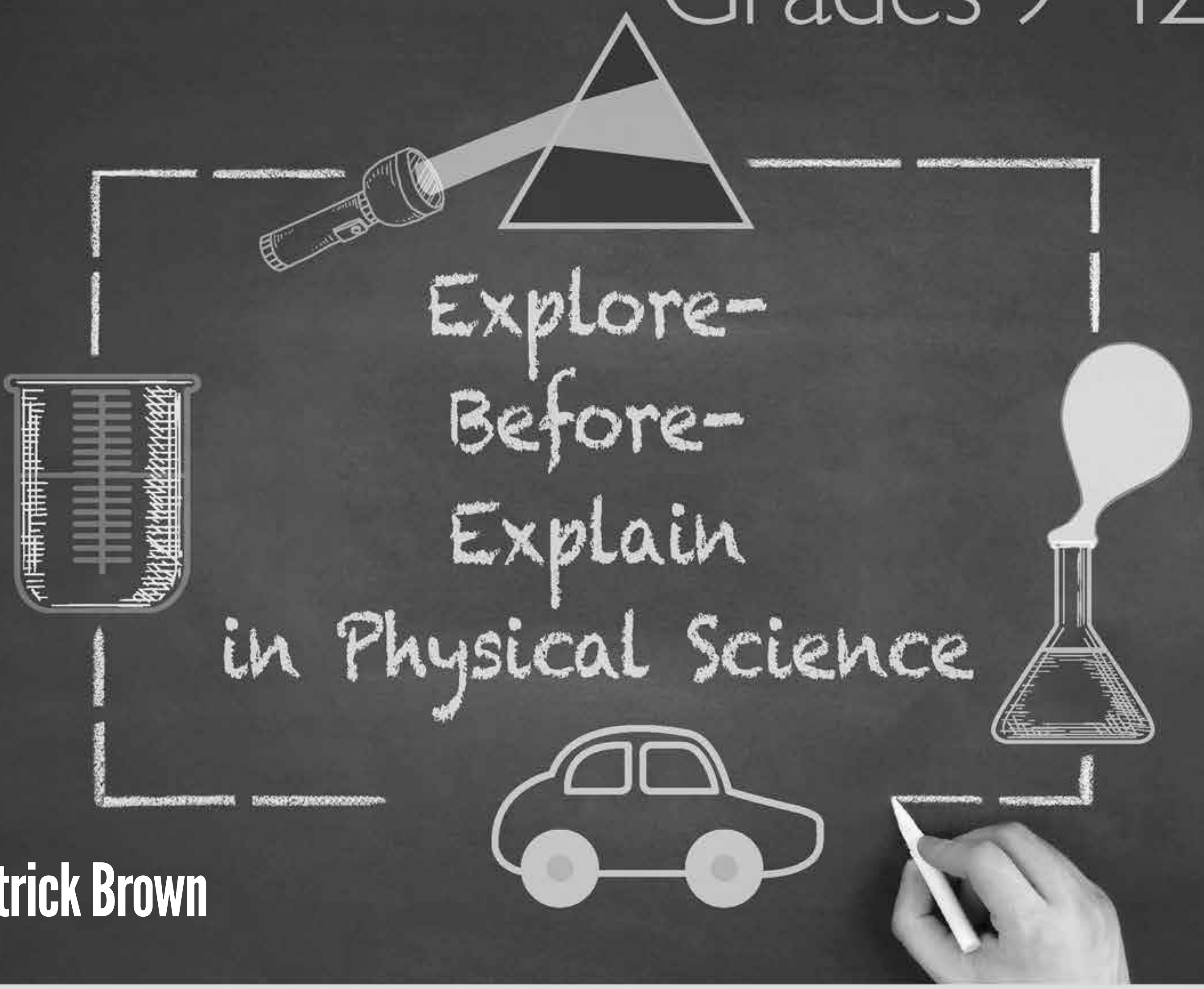

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To Bill and Cathy Feldmann

To quote Albert Einstein, "Few are those who see with their own eyes and feel with their own hearts." You both are among those few. Thank you for all the support!

Contents

Foreword

From time to time, one identifies a new leader, someone the community has not recognized—yet. One hears a presentation at a National Science Teaching Association conference, joins a webinar, or reads an original book and realizes the leadership that is evident. This happened as I read *Instructional Sequence Matters, Grades 9–12: Explore-Before-Explain in Physical Science.*

Patrick Brown provides a wonderful book for science teachers. Not only is *Instructional Sequence Matters, Grades 9–12* a delightful read, but it also is practical and helpful. What more could science teachers ask for? After starting with chapters on mindsets to science teaching and 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 energy, force and motion, waves, and matter and its interactions.

Through the narrative and examples, Dr. Brown encourages teachers to change their mindset 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 mindset for teaching. Why did he embrace this mindset? 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 mindset 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 and plan 5E (Engage, Explore, Explain, Elaborate, Evaluate) lessons that incorporate *NGSS* domains, and recognize that changing one's mindset 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, Grades 9–12* 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)

Acknowledgments

Developing *Instructional Sequence Matters, Grades 9–12: Explore-Before-Explain in Physical Science* required a close look at the research supporting *explore-before-explain* and the *Next Generation Science Standards*. Many thanks to the following people: Dr. Rodger Bybee, whose conversations encouraged me to write a companion book specific for high school teachers; the peer reviewers who did an outstanding job on earlier versions of this manuscript (Anne Tweed, Susan German, Catherine Milne, Ruth Hutson, and Rodney Olson); and Victor Sampson for his thoughtful suggestions and feedback to promote high school teacher thinking and professional learning.

I offer special thanks to Jessica Fries-Gaither for engaging as a thinking partner and reviewing critical parts of this book. Jessica has been a sounding board to bounce ideas off of and brainstorm future writing endeavors.

Finally, in writing this series and this book, I am indebted to the NSTA Press team. I am very appreciative of Claire Reinburg, Rachel Ledbetter, Andrea Silen, and Jennifer Merrill. I have learned these remarkable individuals are talented editors and genuinely compassionate educators who have student learning and the vision of science education reform close at heart. They taught me the importance of emphasizing my skills as a writer rather than viewing my weaknesses as deficits. The success of the *Instructional Sequence Matters* series would not be possible without my NSTA Press team's vision.

About the Author

Dr. Patrick 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, 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

I designed *Instructional Sequence Matters, Grades 9–12: Explore-Before-Explain in Physical Science* primarily for high school teachers wanting to address new standards while ensuring their students leave success-ready. The eye-opening reality is that for some students, these will be the last science courses they take! As you will learn, the *Instructional Sequence Matters* series 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. *Explore-before-explain* teaching acknowledges the critical role that explorations and explanations play in learning. By being strategic about the sequence of instructional activities, teachers can create greater conceptual coherence for students and promote long-lasting understanding. And while there is often a gulf between educational research and direct classroom applications, *explore-before-explain* can help translate research into instructional practice. Thus, this book can serve as a useful resource for professional learning communities (PLCs) and as a guide for professional development workshops emphasizing research-based strategies for science teaching.

This high school version of *Instructional Sequence Matters* retains the strong features of the companion books for grades 6–8 and 3–5. Among these features is an emphasis on the 5E (Engage, Explore, Explain, Elaborate, Evaluate) Instructional Model. In addition, throughout the text, the theme of reform-based teaching is stressed. Included are many examples of seamless translation of *explore-before-explain* teaching and the three dimensions of the *Next Generation Science Standards* (*NGSS;* 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.

Several changes and new features are incorporated for high school teachers. First, I offer planning templates with design questions to encourage thinking in ways that promote the unique combination of *NGSS* dimensions above the content alone (see Chapter 6). The planning templates acknowledge that unique combination of hands-on, minds-on learning that is crucial for learners.

In addition, the model lessons have been greatly expanded to provide a broader exploration of the physical science topics under study. Teachers will learn several strategies for engaging students in tackling engineering design problems (Chapter 7); using algebraic and mathematical reasoning (Chapters 8 and 9); encouraging close reading of technical texts (Chapter 9); developing their own inquiries, called “next step” investigations (Chapter 9); and writing argumentative essays (Chapter 10). The model lessons illustrate that today’s students need a different type of educational experience in light of the ever-changing trends, challenges, and skills necessary for an evolving workforce facing global competition.

Many teachers have come to find that once they have adopted an *explore-before-explain* mindset, this approach promotes powerful classroom learning. Explorations create a context that engages students in science and cultivates their belief that they are essential agents in the creation of knowledge. Context affects learning and motivation. Situating learning in students' explorations and the resulting evidence-based claims gives meaning and purpose to all activities. Students' understandings from both explorations and explanations combine to create meaningful learning experiences, and as a result, they achieve higher levels of science literacy.

Introduction

Every generation is faced with the responsibility of preparing students for the reality of their world. With the current blitz of fast-moving innovations in technology and advances in knowledge, educators are tasked with new challenges. There is a need for educational change in direct response to the dramatic growth of emerging industries and occupations that offer opportunities for anyone who has the skills to take advantage of them. These skills include problem solving, critical thinking, analysis, and interpretation, which are all necessary to be able to make evidence-based decisions based on the best information possible.

Virtually every state is working toward developing high standards related to science education to prepare students for the 21st century. We are seeing something new: a growing commitment to the idea that learning about the content requires that students simultaneously use the skills, practices, and habits of mind valued in the sciences. The rigorous *Next Generation Science Standards* (*NGSS*) are evidence of a growing commitment to providing students with the learning and innovation skills necessary for the 21st century (NGSS Lead States 2013). The *NGSS* promotes three-dimensional learning, which consists of standards related to content (called disciplinary core ideas), practices to engage in science and engineering reliably (called science and engineering practices), and logical thinking skills that cut across disciplines (called crosscutting concepts). The aim of combining these dimensions into standards for science is to emphasize learning by doing. Mastering these standards is important for students not only in science classes but also as they venture into higher education, the workplace, and independent life. It is only when teachers understand these outcomes that we can start to build the supporting educational infrastructure that will elevate student learning to new heights.

The *NGSS* is a set of learning standards, however, and not a prescribed instructional approach. While many advocate the importance of the *NGSS* because they promote active constructivist learning, standards, though necessary, are not enough to improve the education of students. Teachers must now find ways to provide students with the learning opportunities they need to achieve the new standards. Standards might set the benchmark, but teaching must change to advance students on the path of success.

Shifting Roles of Teachers and Students

When we think of the typical classroom, we hope that students are doing the hard intellectual work. Importantly, we must ask who is doing the critical thinking, who is making the evidence-based claims, and who is constructing knowledge. These questions reflect what is necessary to ensure that students are ready for the reality of their world and what it takes to move up the economic ladder. Students with 21st-century skills are better prepared for jobs that increasingly reward people who can adapt and contribute through communications, problem-solving, and critical thinking that allow for customizable solutions and responses to organizational expectations.

Education must help students adapt to contemporary times and be realistic about what they need to be success-ready throughout K–12 and beyond. A look into typical classrooms shows that activities have a standard script, where teacher explanation of content comes first, followed by verification and practice-type activities (Hofstein and Lunetta 2004). This approach fails to promote the logical and critical thinking about data that is needed to articulate the evidence used to explain science. Moreover, it 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 are not an accurate depiction of science (Duschl, Schweingruber, and Shouse 2007). Finally, this sequence places students at the receiving end of learning, with the primary intellectual challenge of confirming and practicing ideas rather than constructing knowledge from firsthand experiences. Arguably, being on the receiving end of learning in a classroom does not prepare students to be success-ready in a knowledge-driven society that requires critical thinking and problem-solving.

A New Mindset 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. Trying to foresee students' future needs is not merely being trendy but is a necessity and should be at the heart of educational reform. *Explore-before-explain* teaching is all about creating conceptual coherence for learners and a response to the need to better prepare students for the reality of their world. An *explore-before-explain* mindset acknowledges that students naturally develop ideas all on their own, while it also highlights teachers' essential role in students' development. The framework is not a prescribed instructional method nor 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 develop. *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 (as well as other adults)—help them develop a more sophisticated understanding.

If we can begin our planning by thinking about experiences students could have that would allow them to construct accurate scientific knowledge, we can more easily situate learning around phenomena, decide what explanations are necessary for students to more deeply understand scientific principles as the science storyline unfolds, and offer elaborations to help make student understanding more sophisticated. The ultimate goal of *explore-before-explain* teaching is to develop students' conceptual understanding because it enables transfer learning. There is too much content to try to teach it all, and we have to be realistic about our goals and the reality of students' worlds.

One favored contemporary way to put an *explore-before-explain* mindset into practice is the BSCS 5E (Engage, Explore, Explain, Elaborate, Evaluate) Instructional Model. Although the focus of this book is on preparing you to be an *explore-before-explain* teacher and design 5E instructional sequences, much of the guidance and professional learning herein can be applied to other highly effective science teaching approaches, such as argument-driven inquiry, inquiry-based teaching, and problem- and project-based teaching, and they can situate learning around socioscientific issues. These approaches are not in competition with one another; rather, you should design learning activities for students based on the teaching context. Draw on your strengths, and do not try to force the use of an approach that is not best suited for the skills and knowledge you want students to develop.

The 5E Instructional Model explicitly sequences science instructional activities so students explore science before elaborating their understanding from explanations; thus, the connection between *explore* and *explain* is fairly straightforward. The 5E came from the three-phase 1960s science learning cycle (Atkin and Karplus 1962; Bybee 1997). In addition, the 5E Model allows students to construct content knowledge using science practices, a productive approach that mirrors how science is done in the real world. Later chapters cover the similarities and differences among the learning cycle 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 5E Instructional Model, 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 in teaching (see Abell and Volkmann 2006). My approach is consistent with their ideas, but at the same time, it is unique.

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 proficiency 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. DOE 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 also evident when looking at their performance on 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 (OECD 2012). Additionally, 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 ranked 11th and 12th, respectively, of all countries tested (IEA 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 looks at students' abilities to answer specific content questions or evaluates 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 learning experience. Though professional development highlights the need for educators to grow individually, professional learning retools this idea so teachers learn how to better serve students (see the Activity Box). The activities that follow will help you with national reform aimed at putting *A Framework for K–12 Science Education* (NRC 2012) and the *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. 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. The book is structured 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 2. (This would be an *explore-before-explain* approach to your professional development!)

Continued

Activity Box (*continued*)

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 (CCSS) for English Language Arts* and *CCSS Mathematics*? 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 intrinsic motivation to keep students engaged?* Representative activities: Can we use common pretests and posttests as well as formative assessments to evaluate 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 lesson studies where we observe one another'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 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). In addition, 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 activities and *NGSS* 3D learning, and they probably will not be perfect right at the start.

Each chapter of this book grew out of research experiences, from working with high school 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 mindset 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 conceptual understanding.

You can use the discussion questions in this book to reflect, both individually and with colleagues, on 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 students' initial discussions after experiencing model lessons. The combination of reflection questions, research chapters, and model lessons strongly supports an *explore-before-explain* mindset.

Chapter 1, "A New Mindset to Science Teaching," presents the importance of knowing about our own mindsets to teaching and how they develop over time. Much of what you will take away from this book is related to your beliefs about teaching and learning. Being cognizant of your beliefs about teaching and learning is important in order to fulfill your potential as a science teacher.

Chapter 2, "Rethinking Development and Learning," summarizes emerging 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. The chapter closes with some suggestions for how to get started.

Chapter 3, "Connecting Hands-On With Minds-On Experiences," compares two different hands-on approaches and shows why the exact placement of activities in instruction is pivotal in learning. It supports the assertions about why *explore-before-explain* teaching is beneficial for learners with abundant science education research that can be further explored.

Chapter 4, "Modern Sequences of Instruction," discusses the key components of two contemporary sequences of science instruction. You will read about the phases of the 5E Instructional Model. 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.

Chapter 5, "Content and Process Working Together," describes the construction of the *NGSS*. It includes some activities for you to reflect on the lessons you currently use and the connections to components of the *NGSS*.

Next, Chapter 6, "Design Tools for Creating 5Es to Make the *NGSS* Come Alive," provides guidance on how you can create 5Es that translate the *NGSS*. It presents activities following each factor that you should consider when planning 5Es and offers some planning ideas to design *explore-before-explain* instructional sequences based on cognitive science research. In addition, the chapter includes planning templates with design questions to help you build 5E lessons.

Physical science lessons for grades 9–12 are found in Chapters 7–10. The model lessons show how to put the *explore-before-explain* mindset into practice using a 5E instructional sequence. As you will come to see, the *explore-before-explain* activities create the science storyline and facilitate the gradual unfolding of related ideas. The model lessons illustrate how the 5E Model easily translates 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 5E Model and the *NGSS* in action.

Chapter 11, "Leadership and Lessons Learned," takes you through five key points for putting an *explore-before-explain* mindset into practice using 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 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' learning will see how they can benefit from a simple reorganization of 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 instructional activities 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 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 opens up opportunities to construct a theoretical model for classroom lesson design so all students achieve 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 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, sanitized, indirectly vented chemical-splash goggles or safety glasses with side shields as appropriate, nonlatex aprons, and vinyl gloves should be worn 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. Also 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, including common items such as baking soda and vinegar, as well as ensure the proper maintenance of all equipment.

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 high school students to review with their teachers and have signed by parents or guardians (*http://static.nsta.org/pdfs/SafetyAcknowledgmentForm-HighSchool.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 10

Arguing About a Chemical Change

Chapter 10

To integrate science and argumentative writing in meaningful ways, teachers can balance students' firsthand science experiences with data and evidence with literacy instruction. I use argumentative science essays as a tool for promoting deep conceptual thinking while teaching students how to write effective argumentative essays. When I first started using writing in science, I expected students to be able to support their ideas with evidence. However, students often have trouble articulating their understanding through writing. When I provided support and broke down argumentative essays into smaller parts, students learned to write in more complex ways while also demonstrating that they had learned difficult science content. Consequently, students' science achievement and writing ability increased. While argumentation writing may take some time, the skills developed are worth the trade-off and can help students in science class, on high-stakes tests like the ACT, and in life.

This lesson addresses the *Next Generation Science Standards* (*NGSS*) physical science performance expectation (PE) that students can "use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction" (HS-PS1-7; NGSS Lead States 2013), as well as all three dimensions of the *NGSS* (see Table 10.3, pp. 122–123). This PE is a ripe area for inquiry, and research shows that students have trouble distinguishing between chemical and physical changes, as well as determining when a substance is conserved during a change (Driver et al. 1994). Even though we do quite a bit of firsthand exploration of signs of chemical and physical changes, it is challenging for students to explore on their own that matter is conserved in a chemical reaction. What follows is an instructional sequence in a ninth-grade physical science class to encourage student learning and show them in a concrete way that mass is conserved in a chemical reaction. This lesson is one step in helping students develop an understanding of the conservation of matter that takes place during a chemical change.

Engage

The purpose of the Engage phase is to situate learning in a meaningful phenomenon while also tapping into students' prior knowledge and experiences. I provided students with a writing prompt (see Figure 10.1).

Figure 10.1. *ACT Writing Prompt for "Is It a Change?"*

Before physical science class began, Mr. Smith gathered the materials necessary for the demonstration, which included an Erlenmeyer flask, sodium bicarbonate ($NaHCO_3$), acetic acid (CH_3COOH), a small balloon, and a rubber band. To prepare for the demonstration, Mr. Smith told students that before class, he had put the sodium bicarbonate in the balloon (15 grams) and placed it on top of an Erlenmeyer flask filled with acetic acid (combined mass 45 grams). He also mentioned that he had created a tight seal between the balloon and Erlenmeyer flask with the rubber band. Mr. Smith showed students the sodium bicarbonate, which students identified as baking soda (students saw the Arm and Hammer box). Students also quickly noticed the familiar smell of the liquid, acetic acid (i.e., vinegar), in the Erlenmeyer flask. He placed the Erlenmeyer flask with a balloon sealed tightly on a scale and recorded the mass on the front board. The demonstration was ready, so Mr. Smith handed each student a sticky note and asked them to make a series of predictions about what would happen when he lifted the balloon, allowing the sodium bicarbonate to fall into the Erlenmeyer flask containing acetic acid. He asked students to include in their predictions what they thought the mass would be during the demonstration. Finally, he told students to provide an explanation for their ideas.

Read and carefully consider these three students' predictions. Each prediction suggests a particular way of thinking about the scientific principles underlying the demonstration.

Riley	Kellen	Chris
I think the balloon will inflate and the mass will be more than before the demonstration. I think the mass will be more because some heat will be produced. Since the heat was not there before, the mass will increase.	I think the balloon will inflate and the mass will be the same. I think the mass will not change because all of the materials are still present, although their form may have changed.	I think the balloon will inflate and the mass will decrease. I think the mass will decrease because when the balloon inflates, it is filled with a gas and gases weigh less than solids.

I wanted students to keep the end goal for learning in mind, so I discussed the essay tasks and scoring criteria. In this way, I was promoting backward design by starting with a clear understanding of our learning goals (Wiggins and McTighe 2005) (see Table 10.1, p. 116).

Table 10.1. *Scoring Guide for Argumentation Writing for "Is It a Change?"*

Category	Criteria	Student Evaluation	Teacher Evaluation
Position Statement	The position statement provides a clear, strong statement of the author's position.		
	All the evidence and examples are specific and relevant.		
	The scientific principles that connect the evidence and position statement are specific.		
	The scientific principles are accurate.		
	The scientific principles are described using appropriate science terminologies/concept/language.		
Inaccurate or Unlikely Perspective	One inaccurate or unlikely perspective is identified.		
	A counterargument is used to refute the inaccurate or unlikely perspective (when applicable, supporting data are provided).		
Additional Inaccurate or Unlikely Perspective	One additional inaccurate or unlikely perspective is identified.		
	A counterargument is used to refute the inaccurate or unlikely perspective (when applicable, supporting data are provided).		
Sentence Structure/ Grammar	The essay is written using complete sentences with no grammar and spelling mistakes.		

Note: This scoring guide is set up as a checklist for students and teachers.

Once students understood the learning expectations and the task, it was time to begin. We started with a close reading of each unique perspective in the writing prompt (see Figure 10.1, p. 115). I asked students to begin with Riley's ideas and evaluate the perspective in terms of the following guiding questions: What insights do the ideas offer, and what do they fail to consider? Why might they be persuasive to others? Finally, I asked students to jot some notes indicating their stance on the strength or weakness of the perspective. Once students were finished evaluating Riley's perspective, they shared their ideas with partners. Students then evaluated the other two student perspectives, those of Kellen and Chris, by using the same guiding questions and shoulder talk with partners. The close-reading activities highlighted key ideas and details in the *Common Core State Standards* (*CCSS*) *for English Language Arts* (*ELA*) related to technical texts that ask students to "determine a central idea of a text and analyze its development over the course of the text, including how it emerges and is shaped and refined by specific details; provide an objective summary of the text" (CCSS.ELA-LITERACY.RI.9-10.2; NGAC and CCSSO 2010).

Based on students' conversations and notes about each perspective, I realized that they did not have a firm understanding of the chemical reaction described in the writing prompt. The reasoning provided in each perspective made logical sense to some students, with the result that students were divided as to whether the mass would be less, the same, or more after the reaction. Interestingly, many students mentioned that they had seen the chemical reaction before in other science classes. Students' comments about their past experiences and incomplete conceptions made me think they needed more opportunities to construct conceptual knowledge from firsthand experiences with data. They had most likely experienced traditional hands-on sequences, which research has shown are insufficient to promote long-lasting understanding (Hofstein and Lunetta 2004; NRC 2000). Students also need minds-on experiences where they make sense of data and a scientific claim that is supported by evidence.

Explore

To delve into whether mass and temperature change during the reaction, we needed to conduct further testing. I used a demonstration to provide a minds-on experience for students (see Safety Notes, p. 118). To investigate changes in mass, I put 3 ml of vinegar in an Erlenmeyer flask. Next, I put 3 g of baking soda into a balloon. I put the balloon on the Erlenmeyer flask, taking care not to allow the baking soda and vinegar to mix. I used some black electrical tape to seal the balloon to the Erlenmeyer flask, making sure there were no gaps. Finally, I placed the flask-balloon setup on an electronic balance.

SAFETY NOTES

1. Both students and teacher should wear sanitized, indirectly vented chemical splash safety goggles, nonlatex nitrile gloves, and a nonlatex apron during the set-up, hands-on, and takedown segments of the activity.
2. Students should sit a safe distance away from the observation table (no closer than 2.5 m).
3. Use caution when working with sharp objects (e.g., glassware), which can cut or puncture skin.
4. Students should have direct adult supervision when working with hazardous chemicals.
5. Immediately wipe up any liquid spilled on the floor, which can create a slip-and-fall hazard.
6. Wash hands with soap and water after completing this activity.

I had students make a prediction about what they thought would happen when I lifted the balloon, releasing the baking soda into the vinegar. Most students knew a reaction would occur because they had seen similar demonstrations in earlier grades. I carefully lifted the balloon, allowing the baking soda to drop into the vinegar. I performed the demonstration on the electronic balance. While the balloon inflated, the mass did not change and remained 26.6 grams (see the YouTube video at *https://youtu.be/gIuJKE6eGpQ*).[1]

The next demonstration was designed to test whether a change in temperature occurs during a chemical reaction. Equal amounts of baking soda and vinegar were placed in beakers. (I used approximately 33.6 g; however, any equivalent amount would work. Although I usually would not measure the mass of a liquid and would use a volume instead, I wanted students to know that we were using the same amount of each substance.) Next, I took the temperature of each solution. The baking soda was 22.0°C, and the vinegar was 21.9°C. When the materials were mixed, to students' surprise, the temperature decreased to 17.6°C (see the YouTube video at *https://youtu.be/uxTsPLgFyo0*).

At this point in the lesson, I wanted students to articulate their understanding through writing. I asked students to make a claims-evidence statement.[2] One student wrote that the temperature decreased but the mass stayed the same in the chemical reaction that occurs when mixing baking soda and vinegar. Thus, students had empirical data and constructed a conceptual claim about the phenomena. Also, students' firsthand experiences supported ideas as they wrote prompt perspectives. Even though students made evidence-based claims, they still wondered why the mass did not change.

1. Although this is a teacher-led demonstration, the experiences engage students in SEPs and they "analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution" (NGSS Lead States 2013, p. 56).

2. Students' experience with data and SEPs helped them "construct and revise an explanation based on valid and reliable evidence" (NGSS Lead States 2013, p. 58).

Explain

Now that students had an understanding of the conservation of mass on the conceptual level, it was time for them to develop a more sophisticated understanding of the chemical reaction that takes place on a microscopic level. First, we explored a PhET simulation on how to balance chemical equations (see *https://phet.colorado.edu/sims/html/balancing-chemical-equations/latest/balancing-chemical-equations_en.html*). Students worked individually to make ammonia, separate water, and combust methane. The simulation helped students see that the number of products must equal the number of reactants in a chemical equation. In addition, students were able to see how the combination of atoms changes in a chemical reaction.

Next, we watched a video of how the molecules interact and recombine during the chemical reaction (see *https://vimeo.com/118456526*). I challenged students to check the equation for the chemical reaction of baking soda plus vinegar by making a T-chart to compare the number of atoms before and after the reaction (see Table 10.2), similar to what we had done in the PhET simulation. (*Note:* I had to explain what the subscript numbers revealed about the atoms involved in the chemical equation.)

$$NaHCO_3 + CH_3COOH \rightarrow CO_2 + H_2O + NaC_2H_3O_2$$

Table 10.2. *Student T-Chart of Atoms Before and After a Chemical Reaction*

Before	After
Na = 1	Na = 1
H = 5	H = 5
C = 3	C = 3
O = 5	O = 5

The combination of the PhET simulation and the T-chart helped students understand the reasoning behind the demonstration and the conservation of mass.[3] In addition, the T-chart helped make the lesson minds-on, as students had to connect their firsthand observations with data to deepen their conceptual understanding. The connection between firsthand observations and explanations helped promote the conceptual coherence of the lesson. The explanation in this unit of study was the first of many that helped students learn about chemical reactions, but this provided the initial exposure and evidence that mass is conserved during a chemical reaction (law of conservation of mass).

3. Students' use of a T-chart to understand a chemical equation helped them engage with an SEP to "use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations" (NGSS Lead States 2013, p. 57).

Elaborate and Evaluate

The Elaborate and Evaluate phase activities occurred in unison. I wanted students to engage in argumentation writing to confirm one perspective and refute another perspective based on data. In this way, students were testing the utility of their ideas in the context of the writing prompt. Students used the scoring criteria in Table 10.1 (p. 116). The scoring guide highlights key components of ACT-type questions, and students had to use their experiences to represent data (30–40% of the ACT) and write about conflicting viewpoints (15–20% of the ACT) (ACT 2018). The writing prompt went beyond using science as a context, with the goal that the process allowed students to develop conceptual knowledge. I wanted students to demonstrate their content understanding by using skills similar to the ones asked for by ACT questions.[4]

To promote their development of conceptual knowledge, I had students type their argumentative essays. I also wanted students to think about their writing in terms of the expectations set out in the scoring guide. I had students color-code their argumentation writing using a highlighting feature in their word processing program to indicate when they were writing about conflicting viewpoints, presenting an accurate claim, providing evidence that supported their claim, and creating a reasoning statement (NASEM 2018). Having students highlight their writing related to the scoring criteria is a beneficial way to help them focus and structure their writing related to the goals of the activity. A representative writing sample with highlighting is shown in Figure 10.2. Their writing emphasized the *CCSS for ELA* that suggests students "Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence" (CCSS.ELA-LITERACY.W.9-10.1; NGAC and CCSSO 2010). The final evaluation phase activity asked students to use the scoring guide to assess their writing. Following students' self-assessments, I scored their writing using the same criteria.

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4. The argumentation writing activity engaged students in an SEP, and they "construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence" (NGSS Lead States 2013, p. 90).

Figure 10.2. *Example of Student Argumentation Writing*

Scientific Explanation

<table>
<tr><th>Conflicting Viewpoints</th><th>Accurate Claim</th><th>Evidence That Supports Claim</th><th>Reasoning Statement</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Of the three predictions, Kellen's ideas are most accurate because he explains that a chemical reaction took place, changing the form of the substances but not altering the overall mass. Both Riley and Chris have inaccurate ideas. Riley thinks that heat will be produced when the two substances are mixed. Heat does not have mass. Therefore, explaining that the mass would increase as a result of heat production is an invalid idea. Chris thinks that the mass will decrease because a gas is produced and "gases weigh less than solids." Chris has a misconception because molecules in gas have mass. Although the substances changed form to produce a gas, the overall mass is conserved and remains constant. In the demonstration, a chemical reaction took place between the sodium bicarbonate and acetic acid. When the two substances are mixed, they produce carbon dioxide, a gas, which inflates a balloon, but the overall mass remains unchanged. The beginning mass of the substances combined is approximately 45 g. During the demonstration, the mass does not change and will remain 45. The demonstration shows a chemical change taking place, and the law of conservation of mass is the underlying principle shown in the demonstration. Although the form of matter changes, as evidenced by the production of a gas from a solid (sodium bicarbonate) and a liquid (acetic acid), the mass does not change.</td></tr>
</table>

Conclusions

Many districts are pushing for change in the way all subjects, including science, are taught to better prepare students for college admission exams such as the ACT. Interdisciplinary instructional approaches will be needed to assist students in developing proficiencies in test-taking strategies required for the ACT. The combination of learning about chemical reactions and creating a T-chart for minds-on conceptual understanding helped students combine their macroscopic observation of phenomena with a macroscopic explanation. Even though teachers have been mixing baking soda and vinegar to demonstrate chemical reactions for some time, the *explore-before-explain* sequence and focus on argumentation writing are a way to maximize learning and address the three dimensions of the *NGSS*. In this way, the lesson highlights cognitive science research that shows that the learner-centeredness, assessment-centeredness, and knowledge-centeredness of a classroom are essential factors for best possible learning environments (NASEM 2018). Connections between the lesson and the *NGSS* are shown in Table 10.3 (p. 122).

Table 10.3. *Unwrapping the Standards in Chapter 10*

HS. Matter and Its Interactions	Connections to Classroom Activity
Performance Expectation	
HS-PS1-7: Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.	Students conduct an investigation in which baking soda and vinegar are mixed in relation to chemical equations to learn about conservation of mass.
Science and Engineering Practices	
Asking questions and defining problems	Students engage with questions about mass and temperature as they carefully test their predictions about observable phenomena.
Planning and carrying out investigations	Students engage in an investigation to gather evidence on whether a chemical reaction occurs when mixing baking soda and vinegar. During students' investigation, they collect quantitative data on mass and temperature.
Analyzing and interpreting data	Students analyze changes in data to formulate an evidence-based claim.
Using mathematics and computational thinking	Students measure data to determine whether patterns exist that suggest a relationship. In addition, students inventory different atoms in a chemical reaction to infer whether mass is conserved.
Constructing explanations and designing solutions	Students construct an evidence-based claim to explain their observations of the law of conservation of mass and indicators of chemical changes.
Engaging in argument from evidence	Students use data gathered from what they witness firsthand to confirm or refute different ideas that could make logical sense.
Obtaining, evaluating, and communicating information	Students write an argumentative paper that conveys an evidence-based claim and also refutes common misconceptions.

Continued

Table 10.3. (*continued*)

HS. Matter and Its Interactions	Connections to Classroom Activity
Disciplinary Core Idea	
PS1.B: Chemical Reactions The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	Students' firsthand experience with the graduated cylinder–balloon demonstration provides evidence that mass is conserved in a chemical reaction.
Crosscutting Concepts	
Patterns	Students look for patterns in data to determine whether a change occurs when baking soda and vinegar are combined.
Cause and effect	Students investigate the relationships among atoms using their macroscopic observations to explain change and the factors that stay the same or are different before and after a chemical reaction.

Note: The materials, lessons, and activities outlined in this chapter are just one step toward reaching the performance expectation listed in this table. Additional supporting materials, lessons, and activities will be required. See *www.nextgenscience.org/pe/hs-ps1-7-matter-and-its-interactions* for more information.

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