AMBITIOUS SCIENCE TEACHING

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Preface

Ambitious Science Teaching (AST) represents a vision for changing how children learn about the natural world. It focuses on the ideas and other diverse resources that they bring to classrooms every day, as building blocks for sense making and progressive knowledge building. This vision is built on a repertoire of teaching practices that cultivate student dialogue, community reasoning, and intellectual rigor, as well as the ability to learn how to learn. As promising as this sounds, we would prefer that when you read each chapter of this book, you be critical of our theories and tools—to be sure that the evidence is clear to you and is compelling enough for you to consider changes in your teaching. To accommodate this, we now share the origin story of AST, including the fits and starts that made the journey interesting.

Many years ago, long before the idea of Ambitious Science Teaching started to take shape, we were reading everything we could get our hands on about instruction that had significant impacts on student learning. Researchers in diverse fields of study were starting to describe how, under the right circumstances, children in science classrooms could explain, model, argue, design investigations, and problem-solve with one another, in ways that went far beyond the expectations built into common curriculum and standards. We became excited about the possibility of translating and applying outcomes from these studies, largely done under controlled conditions, to the dynamic environments in which science teachers work.

We were not the only ones trying to make these connections, but we felt confident about our prospects, in part because we had spent years as science educators ourselves and understood the challenges of teaching in underresourced schools with precious little time to experiment with peers about instruction. All three of us were at the University of Washington and in charge of preparing novice teachers for work in secondary science classrooms. We believed that our own courses on methods of instruction could be incubators for testing out innovative forms of practice and then seeing how these worked with young learners in local schools. Our preservice teachers were eager to learn about alternatives to the status quo, so we obliged them and spent months explaining in great detail what research indicated they should be doing to foster student engagement and authentic science activity. We later followed these novices into their host classrooms to observe the fruits of our labor. We were all disappointed.

Our exuberance about adventurous teaching and our novices' willingness to try out new and unfamiliar routines did not translate into eager student participation or the learning outcomes that the research literature had promised. Most of the exasperated teachers-in-training said things like "I knew *what* I wanted to have happen, but didn't know *how* to make it happen."

We realized then that we had relied on broad notions like "inquiry" and "hands-on work" to shape their attempts at teaching, and had failed to show our novices actual practices—that is, approaches that you could see and hear someone using in a classroom on a regular basis. What was needed were professional routines that were recognizable, principled, and improvable. This realization prompted us to specify instructional practices from the research literature, which required some inventiveness because they were not clearly identified there. We ended up selecting a small number that appeared critical for student learning and participation, gave them names, and aimed to get our novices proficient at them. Each of these practices was really a combination of tasks, talk, and tools that had to be used together to support knowledge building. At this point, we didn't want to repeat our earlier mistakes by simply *telling* our novice teachers what powerful practice was, we had to *immerse* them in it. So, we played the role of the teacher while our novices became the students. They then took their turn in the teaching role during what we and others call *rehearsals* (that's another book). In retrospect, we can clearly see that there is no substitute for live action in which our own instruction becomes public, responsive to the science ideas of everyone in the room, and open to critique. Weak spots in teaching, ours and theirs, became glaringly obvious, but the benefits were that everyone learned quickly what was possible, and how to improve. To our delight, these practices "traveled" much more readily into K–12 classrooms.

We are oversimplifying the story, but these events started a twelve-year run of experimenting with our novices, and increasingly with local teachers, around a set of core practices and the tools to go with them. These resources now get "tested" by hundreds of colleagues—both experienced and preservice educators—on a daily basis.

Other surprises followed. The core practices were originally designed for middle and high school instruction, but elementary teachers soon began pushing the limits of AST with five- and six-year-olds. We were astonished to see what was happening in their classrooms. Teachers had to adapt most of our tools, using fewer words and more pictures, but even the youngest of learners, they found, were capable of experimenting, making sense of data, and revising explanations over time. We recently observed boys and girls in a second-grade classroom create different claims for why a nearby town was nearly wiped out by a flash flood, despite only modest rainfall in the area. The diversity of their initial ideas was impressive enough, but then a few days later these young learners evaluated their claims using maps, evidence from readings, their own "sandbox" tests, data collected by scientists, and known science facts. Although such episodes never unfold without unexpected problems and require lots of support, teaching like this is still extraordinary—and slowly but surely making appearances in classrooms around the country.

The AST community is now more focused than ever on finding ways for *all students to participate* in challenging science, to make science *compelling to wider groups of learners*, and to *provide the means for students to show what they know*. If we are going to turn a corner on how science is taught, we have to be serious about including every learner in the classroom and recognizing that children *have many legitimate ways of making sense* of the natural world. Traditional teaching does not often accommodate diverse pathways to deep understanding. This stance about equity, we believe, sustains our colleagues through a lot of hard work—hard because it requires new knowledge and skills, but also because we are now trying to teach in ways that we never experienced ourselves as learners.

We dedicate this book, then, to professional educators around the country who have taken risks to make a difference for their students. Some of them use AST, some do not. We also wish to thank our current and former research assistants and postdoctoral researchers who have shared the frustrations and

the joys of this ongoing project. You have been great colleagues: David Stroupe, Carolyn Colley, Sara Hagenah, Michelle Salgado, Karin Lohwasser, Christine Chew, Hosun Kang, Christie Barchenger, Kat Laxton, Biz Wright, Soo-Yean Shim, and Jen Richards.

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ONE

A Vision of Ambitious Science Teaching

EVERY YEAR, IN AN INCREASING NUMBER of schools across the country, science educators come together with colleagues to plan for significant changes in the ways their students will learn science. These professionals may be motivated by new approaches to teaching that challenge their current conceptions of what's possible in classrooms, or they may be unsettled by their students' chronic disengagement. Likely a bit of both. Regardless of the call to action, when teachers make the decision to improve instruction together, they have to put two questions on the table: What do we want to get better at? How do we go about changing our practice in systematic ways?

While there are never straightforward answers to these questions, successful efforts at change are always influenced by a *coherent vision of instruction* that incorporates both rigor and equity into the work that teachers aspire to do with students. But where does such a vision come from, and how does it get translated into action that we can see and hear in classrooms? This book provides a roadmap for innovation by describing how research can inform decisions teachers make every day, to shape conditions of learning for their students.

For the past thirty years, educational researchers have been studying the circumstances under which students engage with science ideas and interact with each other as they do authentic disciplinary activity together. Countless teachers have been observed and data collected in their classrooms, many of these in high-needs schools. Important questions have been asked, such as: Who is participating? Who is not? What, exactly, are students learning? What changes in teaching or in classroom conditions result in learning benefits for students? Are young learners capable of more than what current forms of teaching can support?

In some cases, researchers identified effective teachers and documented how students responded to their classroom norms, instructional routines, and high expectations. In other cases, researchers teamed up with educators to redesign the classroom environment or construct new curricula in order to enhance students' engagement and learning. As a result of all these efforts, stories emerged from classrooms where students were consistently pushing beyond the boundaries of what we consider typical school science. Seventh graders, for example, were observed piecing together increasingly complex explanations for how genetic and environmental factors interacted to drive up the rates of diabetes in their community. Juniors in a chemistry class were developing models for the spread of ocean acidification, using historical measurements of atmospheric gases, data from solubility experiments they had run, and information from scientific journals about global warming trends. And in a kindergarten classroom, five-year-olds took turns arguing whether gravity should be added to their stories about "how someone little can bump someone big off the end of a playground slide."

What made these powerful examples of learning were not the clichéd episodes of students working excitedly with beakers and microscopes or the rhetorical drama of whole-class debates. Rather, the really remarkable things were less visible. For example, a *majority* of learners in each classroom participated in the activity and sense-making conversations each day. Students were used to *sharing their thinking* with classmates, and were expected to *revise their science ideas* over the duration of a unit. Teachers provided *scaffolding* for everything from explanation writing to critiquing someone else's idea, and many educators were notably skilled in *managing productive and equitable talk* by their students.

All these trends were promising, but like pieces of a large and complicated puzzle, they needed to be assembled to form a bigger picture. Up to this point they had not been organized in a way that helped teachers apply the research findings to plans for better instruction in their classrooms. Instead, recommendations from the literature have seemed like a patchwork of loosely connected claims that didn't address the full scope of how teachers need to work with their students in order to achieve important goals. In many cases, the advice has been too theoretical to be usable or has been translated into slogans.

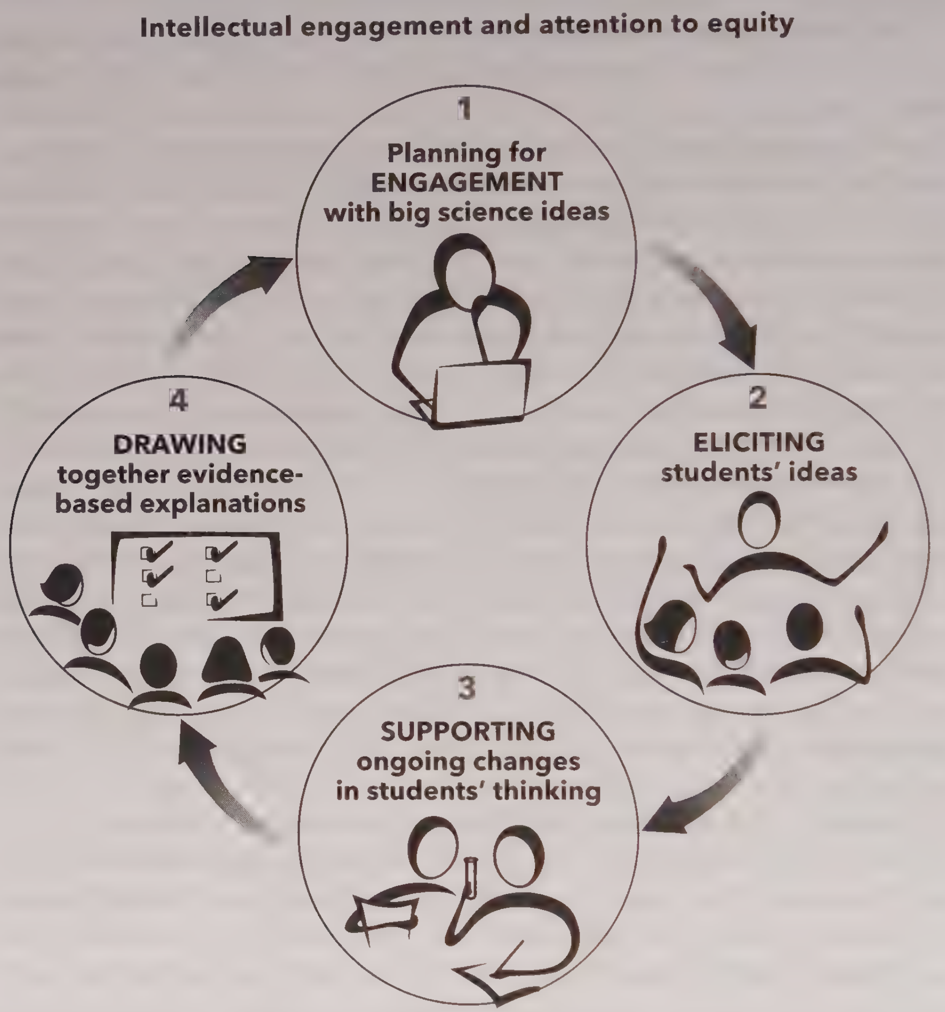
This picture has now changed. With this book, we introduce *Ambitious Science Teaching* (AST) as a coherent and accessible vision of what highly effective science instruction can look like. AST represents a synthesis of recommendations from many types of research studies. The goal of AST is to help students of *all* backgrounds to deeply understand fundamental science ideas, participate in the practices of science, solve authentic problems together, and learn how to continue learning on their own. The kind of teaching required to achieve these goals is adaptive to students' needs and thinking, and maintains rigorous standards for participation and performance by everyone in the classroom. More importantly, the practical ideas that make up this vision have been tested in a wide range of classrooms, and they continue to evolve as teachers use them.

Ambitious Science Teaching, however, is not a label for just any kind of roll-up-your-sleeves "good" instruction, nor is it a list of vague prescriptions. The core of this framework is made up of four sets of teaching practices (see figure 1.1). By "practices" we mean regularly recurring teaching activities that are devoted to planning for, enacting, or reflecting on instruction. The first is a set of planning practices that are used to design challenging and coherent units of instruction; the other three sets of practices come into play as you teach the unit, and require different kinds of intellectual work by students. Each set of practices comes with its own subset of tools, tasks, and opportunities for sense-making talk.

You are likely wondering why there are only four sets of practices. The answer is this: To make fundamental shifts in teaching, you have to invest yourself in practices that make the greatest difference for your students' participation and learning. If there were dozens of random strategies involved, you would be diffusing precious time and energy becoming acquainted with all of them, and you still wouldn't be sure if or how they could be used together in your classroom. In contrast, if you focus on a core group of practices—a set that works together—you can seek mastery of a few types of interactions with students that have the greatest promise for their academic success.

The other reason for concentrating efforts on four sets of practices is that it allows groups of educators who take up AST to start speaking the same language about instruction. When educators adopt a common language about teaching, they can more readily share their experiences with these practices, describe

FIGURE 1.1 Ambitious Science Teaching framework



variations that work for their students, or talk about tools they've developed to support these practices. In other words, they can start to learn from each other, even as they "change" what AST looks like in their local context. So, when we refer to the continual improvement of teaching, we mean not just that individual educators become more advanced in their practice, but also that science teaching among groups of professionals is transformed over time.

The claims we make come from the fact that we've been working with hundreds of science teachers over the past twelve years on these practices. We were science educators ourselves (K–8 and high school) and are currently faculty in research universities. But the story of Ambitious Science Teaching has been written largely by our classroom colleagues. They have tested these core practices in high-needs schools with thousands of students; they have rejected some of our early tools as well intentioned but unwieldy in real instructional situations, and then created more effective ones in their place; and they have reconstructed some of our initial practices to be more effective for a wider range of students, including English language learners (ELLs) and other children on the margins of the science classroom. They continue to adapt AST while holding close to powerful research-based principles of rigorous and equitable teaching.

Our colleague-partners in the field have also *deprivatized their teaching* so that they can observe each other taking risks while working with students in unfamiliar but promising ways. This goes against the grain of traditional school culture, which has been characterized as an "egg crate" model of professional work-life—each teacher nested in his or her own classroom with little access to others who might provide glimpses of alternative and useful practices. If we aspire to the continual improvement of teaching, then opening up our classrooms to others is crucial. So the lessons we've learned about improvement efforts can be summed up this way: transformative teaching is the outcome of (1) focused work, (2) with colleagues, (3) on things that matter for student learning, (4) over time. Let's take a closer look now at what AST looks like and sounds like in classrooms.

WHAT WOULD WE SEE AND HEAR IN THE AST CLASSROOM?

We've claimed that AST is informed by research, but such assertions get tossed around a lot in the world of education, so we want to clarify what this means in the context of our framework. Because of the social dynamics of classrooms and the complexity of learning itself, no research study can ever definitively say, "Here is the key to teaching."[1] Rather, researchers analyze dozens or hundreds of similar investigations and look for trends that convince them if certain conditions are in place in classrooms, or if teachers routinely make particular kinds of moves with students, then over time there is a greater chance that more students will participate in more meaningful ways, and have more fruitful opportunities to learn. The best we can do is increase these probabilities. Sometimes our influence is in the short term (a kind of question we ask a student) and sometimes it unfolds over months (gradually building students' identities as knowers of the natural world).

So where should we place our bets? What does the research say that can be translated to teaching? We've identified seven elements of rigorous and equitable instruction by cross-referencing different bodies of research (for example, studies of how students learn, studies of expert teaching, studies of how knowledge is constructed within the discipline of science, and studies of how equity can be fostered in classrooms), and we express these as "what you'd see and hear" in an AST environment, regardless of whether it is elementary, middle, or high school. What we share next are not the practices themselves that we mentioned previously, but rather broad conditions of instruction that characterize AST; in other words, these elements form the foundations of the practices. As you read them, you'll likely notice that these elements have to work together to be effective; they cannot be used in isolation.

1. Teachers Anchor Students' Learning Experiences in Complex and Puzzling Science Phenomena[2]

For much of an instructional unit in the AST classroom, students focus on an unusual event or process in the world that they will build explanations for by coordinating different science ideas with logic and evidence. A group of fifth graders studying sound, for example, might try to explain how a singer can break a glass with just the energy from his voice. A group of ninth graders studying ecosystems might be figuring out what factors are contributing to the decline of killer whale populations and what might be done to restore balance among biotic and abiotic parts of their habitat. A class of twelfth-grade physics students might learn how forces and motion work by exploring how an urban gymnast can run up to a wall, plant his foot on it, do a backflip, and land on his feet. Students' explanations for all of these phenomena are intended to be detailed, elaborate, and backed up with multiple forms of evidence. Most, but not all, of the unit's activities are directed toward these aims.

2. Students' Hypotheses, Experiences, Cultural Knowledge, and Questions Are Treated as Resources to Help the Class Build Toward Big Science Ideas[3]

In the AST classroom, teachers work with and on students' ideas. *Working with* ideas means that teachers elicit students' initial understandings of a puzzling phenomenon or a driving question that anchors the unit. At first, students typically offer partial and fragmented explanations; they may also reference outside-of-school experiences or cultural knowledge they feel is relevant. We refer to all of these as *resources*. Occasionally these resources provide novel viewpoints that were not anticipated by the teacher, but nonetheless they provoke new kinds of reasoning by the class. The teacher's role is to prompt students to think out loud, to help them organize rough-draft ideas and represent them back to the class as "what we think we know for now," and to record questions that students are interested in. *Working on* ideas means that, throughout the unit, the teacher will invite students to use their prior academic knowledge, outside-of-school experiences, and even new questions to help the class revise and elaborate on their current explanations. Teachers keep the canonical science in mind during lessons, while at the same time listening for student contributions that have the potential to support everyone's reasoning in unexpected ways.

3. Students Use Ensembles of Scientific Practices for Testing Ideas They Believe Are Important to Their Developing Explanations and Models[4]

Students in an AST classroom pursue the long-term goal of constructing coherent and evidence-based explanations of complex phenomena. Science practices such as asking testable questions, modeling, designing and carrying out investigations, and arguing from evidence are essential to achieving this goal. Even the youngest of students can engage in these science practices if they understand the role that each plays in the larger enterprise of improving ideas, and they are apprenticed into using these practices together in order to make sense of a puzzling event. Apprenticing means that the teacher helps students participate in authentic disciplinary practices, but takes initial responsibility for the more challenging and unfamiliar aspects of the work. Over time, learners take on more central roles in the activity and decision making, with the help of feedback and other kinds of support from the teacher.

4. Teachers Provide Varied Opportunities for Students to Reason Through Talk[5]

Research studies from many different fields confirm that student talk is the primary vehicle for their sense making. Teachers engaged with rigorous and equitable instruction help their students understand the "rules of the game" for different kinds of conversations and provide tools to help them learn to participate in more productive ways over time. These tools include student-generated norms for talk (e.g., how to disagree with a peer's idea or ask for clarification), routines that structure how partners can share ideas as well as listen actively to one another, and debriefings with students about how they could improve the quality of small-group and whole-class conversations.

5. Students Have Access to Specialized Tools and Routines That Support Their Science Writing, Talk, and Participation in Activity[6]

Students in these classrooms are stretched to communicate in ways just beyond what they are currently capable of, and this is where scaffolding becomes critical for the improvement of valued performances. Scaffolding takes many forms. A teacher might, for example, provide sentence frames to help students question each other about progress during group work, or the teacher might think out loud about the steps a person should consider in designing an experiment. In some classrooms students are provided with different examples of how scientific explanations are revised based on new evidence. Young learners are routinely challenged to engage in complex performances, but these become manageable because the teacher provides just enough structure, in the right places, to do the work.

6. Student Thinking Is Made Visible and Subject to Commentary by the Classroom Community[7]

The teacher engaged in rigorous and equitable instruction periodically assembles students to do work together as a community that could not be accomplished by individuals alone. Students are asked to share knowledge products that depict their current thinking; these can be models, conceptual drawings, or partial explanations. These representations are often selected by the teacher for their potential to prompt whole-class dialogue. The conversations can then focus on one of several goals, such as comparing different ways of constructing explanations for the same event, unpacking the meaning of a science concept, or commenting on how a student's model was changed in response to new evidence. In the process, everyone has a chance to hear how peers are reasoning about problems and to pick up examples of "what counts" as a science claim, a credible argument, a causal model, or an evidence-based explanation.

7. Learning Experiences Are Selected to Help Students Build Toward Cumulative and Nuanced Understandings of Big Science Ideas[8]

Students in AST classrooms learn that their thinking is supposed to change over time—to be revised and made more coherent in response to new experiences. This is a major shift from the common schooling goal of being correct about "the idea of the day" or reproducing, by rote, knowledge that is in textbooks. In AST classrooms, students spend significant time conducting investigations, discussing readings, taking notes during interactive mini-lectures by teachers, and working on lab activities. Each of these episodes is intentionally designed to illuminate some part of a complex problem or event. Students come to expect that they'll have to integrate ideas from multiple lessons in order to genuinely understand the science.

How These Elements Work Together to Influence Opportunities to Learn

As you read about these elements, you probably noticed that they would work most effectively in combination with one another, rather than as stand-alone conditions. For example, if you want to use students' ideas and experiences as resources for learning in your classroom (second in our list), you will have to encourage open discourse (fourth in our list). If you want to make students' thinking visible so they can collectively work on one another's ideas (sixth), you'll need to structure how they present their works in progress or demonstrate how to offer public critique to a peer (fifth). And engaging in authentic disciplinary work (third) to explore ideas that change over time (seventh) is best accomplished when students are trying to figure out complex problems (first). Each element, then, is part of a larger organic experience that fosters a sense of intellectual community and challenge for students.

All of these elements also appear in various standards for professional practice and evaluation—for example, the Danielson Framework and National Board Certification rubrics (see appendix A for an analysis). Much of the same research literature that informed these documents has also been used to shape AST.

THE CENTRAL ROLE OF EQUITY IN AMBITIOUS SCIENCE TEACHING

Equity is often thought of as providing every student with similar opportunities to make academic progress. But this definition is misleading; it suggests that exposing everyone in the classroom to the same well-crafted activities or clear presentations of information qualifies as both effective and fair. What's missing? In equitable classrooms, the teacher also *provides the means by which all groups of students can take advantage of situations that are designed to support learning.*

Here's an example. We may take for granted that a captivating lab with homemade batteries will illuminate ideas about energy storage and energy transfer for every student. However, the prereading you give out about positive and negative charges may be impenetrable for learners who speak a primary language other than English, and the expectations for interacting verbally with partners about these ideas are similarly daunting—that is, unless these learners are allowed to team up with an ELL peer whose reading and speaking skills are a bit more advanced than theirs. This simple move may be all that's necessary to transform an exercise in frustration into a productive episode of learning.

Without attention to equity in instruction, some students come to believe that science is like a foreign language, convincing themselves that "I am not the kind of person who does science," or "science is just not relevant to my life." Boys and girls who struggle in the classroom do not always have learning issues; they may simply need access to basic tools, language, supports, or extra time to make challenging work more tractable. A disproportionate number of these students come from poverty-impacted, immigrant, or special needs backgrounds. For these groups in particular and all students in general, rigor is not possible without the supportive means to achieve valued goals. Because concerns for equity are so important to instructional excellence, they are woven into Ambitious Science Teaching. But we need to intentionally call out the different ways that AST supports equity so that these threads don't get lost when teachers develop variations of the core practices or create new tools for their classrooms. So let's be clear.

First, we believe that teachers should, to the degree possible, *situate learning in familiar or everyday contexts*, choosing events for study that are related to students' experiences and interests. These can be real-life science phenomena that happen in the community (e.g., local ecosystem disturbances), in homes (e.g., chemistry of food preparation), within families (e.g., how similar but non-identical physical traits appear in siblings), or at school (e.g., soundproofing the gym). These highly contextualized situations are preferred over generic textbook tasks because they allow students from diverse backgrounds to use their out-of-school knowledge as they participate in building explanations or solving problems. Students often feel additional relevance when issues of social justice are involved, such as the impact of poverty on diet or climate change's effect on vulnerable human populations.

As instruction unfolds, teachers are *responsive to students' ideas, experiences, and questions.* The teacher welcomes local knowledge that students from varied backgrounds bring to class discussions. Students' ideas are treated as legitimate mini-theories, and even their partial understandings are framed by the teacher as possible resources for the entire class to work with. Occasionally, teachers can adapt lessons to take advantage of student experiences or puzzles that they believe are relevant to the science being studied.

Because authentic science activity and talk are central to AST, *teachers make explicit to students how scientists generate and defend claims for knowing, and the norms for participation in disciplinary conversations.* Many students from non-dominant communities do not participate in science classrooms because they are unfamiliar with these "rules of the game"—meaning those valued in traditional Western science. When teachers describe ways to contribute to various kinds of discussions and model their own thinking about how to enter a conversation, they allow more students access to small-group and whole-class talk. These teacher moves reinforce norms for respectful and accountable whole-class dialogue, making students feel safe about participating. With this help, students more readily see the similarities and differences between everyday conversation and more academic conversations, and over time, recognize when to shift from one to the other.

Teachers routinely *use specialized forms of scaffolding* for reading and writing, providing structures for learners to interact with others around intellectual work, and adapting tasks for diverse learners (as we described in the previous section). These opportunities are sometimes made available to an entire class; at other times they are tailored or differentiated to meet the needs of particular students.

As instruction unfolds, *teachers honor students' sense-making repertoires.* Students from various ethnic, social class, and racial backgrounds often employ metaphors, storytelling, and physical action to express and debate sophisticated science stories. These valuable ways of reasoning and communicating are different from the predominant modes of concrete descriptions, classification talk, and stepwise explanations that are more traditionally used to express science knowledge in school settings. Regardless of how knowledge is represented by students, the teacher acknowledges that there are many ways of knowing, and that these can offer unique perspectives on the phenomenon or event being explained. Some of these ways of knowing are grounded in culture (e.g., how indigenous communities explain the relationships between humans and other living things in the natural world) and are treated as legitimate, even though they differ from common school science explanations.

Teachers *use frequent formative assessments that allow students to show what they know* (through combinations of speaking, writing, drawing, etc.). This is preferred over an exclusive focus on tests and quizzes that largely identify what students don't know. Many young learners feel enormous pressure when faced with tests, and don't get any useful information from completing them, other than being assigned a grade. Formative assessments, on the other hand, can tell students where they are currently in their understanding about science ideas, and what they might need to work on. This focused feedback benefits all learners, but in particular those who seek meaningful understanding and/or who struggle with communicating what they know.

These equity features of AST all contribute to learning, but they can be too easily overlooked or considered nonessential. We don't want to fall into the trap of seeing equity as occasional acts of care and kindness directed toward students who "need help" (a deficit point of view). Equity is instead a characteristic of the instructional environment that increases the capacity for *everyone* to participate in meaningful learning activity, and requires wide-ranging professional skills to sustain each day. Equity is a moral imperative, but it is also immensely practical. More of your students will feel that science has something to do with their lives, and that their lived experiences are valuable levers for understanding science; more of your students will understand and appreciate the aims of science lessons; fewer students will push back from the table in frustration when confronted with challenging tasks; more will believe they can do the work, or if they can't, they'll know that they're in a classroom where help and resources are always there for the asking. For all these reasons, we recommend that you treat equity as foundational to your teaching.

HOW THIS BOOK IS ORGANIZED AND HOW TO USE IT

Chapter Arrangement

We start with the first of four core sets of teaching practices (planning for engagement with big science ideas, eliciting students' ideas, supporting ongoing changes in thinking, and drawing together evidence-based explanations). Chapter 2 explores how to plan at the unit level, and in particular helps you identify what the big science ideas are that students should understand deeply. This is also where you'll find guidance about selecting an anchoring event and crafting an essential question that students will start with (they will develop their own science questions along the way).

We then shift to two chapters on classroom discourse, because managing productive forms of talk is fundamental to the remaining practices that make up AST. Chapter 3 provides a basic vocabulary for the different kinds of talk moves that can be used in conversations and how such moves can be used to serve important learning goals. These include probing, pressing, revoicing, follow-ups, wait time, and others. We illustrate how different teachers, using the same lesson plan, create widely varying opportunities for students to reason individually and together, depending upon how they deploy these talk moves. Chapter 4 lays out conditions that help all students feel able and willing to participate in classroom conversations. As you might imagine, just having a set of teacher talk moves does not, by itself, transform learning. You'll need to incorporate norms, create scaffolds for different kinds of talk, use strategies for dealing with silence, prompt reluctant students to join in conversations, and encourage students to address each other rather than always communicate "through you."

Chapter 5 lays out the second core set of teaching practices, about eliciting students' ideas and activating their prior knowledge. These practices are often used on the first day of a unit so you can find out how your students reason about the big ideas and what experiences they are bringing in from outside the classroom to make sense of the topic.

We then devote chapters 6 and 7 to the scientific activity of modeling. Modeling (together with explanation) is at the heart of knowledge building in the discipline. Research confirms that, through modeling, students can understand science concepts and learn how ideas evolve, using evidence and new information. Unfortunately, modeling is a structured activity that few teachers have ever experienced as learners. It has never been part of common practice in science classrooms. These are good reasons for you to explore both the chapter on how to help students create initial models and the follow-up chapter on revising models with evidence and ideas.

Chapters 8, 9, and 10 explore the third set of core teaching practices, designed to prompt changes in student thinking about science ideas that are embedded in the anchoring event. This is where activities like investigations, readings, and lab work are used. Although these are familiar to most teachers, the way they are used in combination with talk to shift students' ideas is not at all common in classrooms today. We devote one full chapter to each core teaching practice in this set.

In chapter 11 we introduce science argumentation. Lessons that include activities and introduce ideas often result in discussions of evidence for existing explanations, and new claims by students. We lay out a basic vocabulary for scientific argumentation and provide a number of scaffolds that you can use with students.

The final set of core teaching practices is addressed in chapter 12. Here we show how to help students work together as a scientific community to draw upon ideas and evidence from multiple lessons as they make revisions to their current explanations and models. This set of practices is typically used once in the middle of a unit and again at the end of a unit.

To help you see how the core teaching practices are used together in a unit of instruction, we call your attention to appendix B. We use two classroom examples that reappear throughout the book: the story of a fifth-grade classroom where students are investigating how a singer can break a glass with just the sound from his voice, and a tenth-grade classroom where students are investigating how the Yellowstone ecosystem could be drastically altered by the reintroduction of wolves.

The book would not be complete without chapter 13, on organizing your colleagues for change. To innovate in the classroom, you need collaborators to take risks with and play the role of critical friends. Together, you can design pedagogical experiments and test hypotheses about what kinds of teacher moves or classroom routines result in greater participation and learning by students. Rough attempts at new practices can be analyzed from multiple perspectives and reworked more successfully by teams than by individuals. In this chapter we share a framework for studying and improving practice with peers.

We finish with chapter 14 by exploring an important question: Can we be ambitious every day? Here we address frequently asked questions about which parts of AST students should experience multiple times over the course of a year, which practices should make an appearance every week in one form or another, and which should be part of teaching every day. We also describe other effective frameworks for teaching (project-based learning, teaching for social justice, integrating history and science, participating in citizen science, etc.) and share how AST tools and routines can be integrated into these models of instruction to enrich the sense-making discourse, allow more students to participate, and keep the focus on big ideas.

Tools to Get the Work Started

Embedded in each chapter are examples of tools that we and our teacher collaborators have developed over the years. By "tools" we mean materials that guide or organize different types of valuable work, either by you or your students. These are remarkably useful in helping you make the shift to AST and engage your students in more challenging activity. The tools fall roughly into four categories (see appendix C for a more complete taxonomy of these tools).

- *Planning tools* help you use curriculum and standards documents to identify the big science ideas that you and your students should be spending the most instructional time on. These tools also help you develop or select anchoring phenomena and then sequence learning opportunities for your students in ways that allow them to develop cumulative and coherent understandings of these events or processes.
- *Face-to-face tools* are used with students to represent and work on *their* current ideas. These representations are often put on the walls of the classroom so that students' current thinking can be *made public and revised* over time. So, these tools don't just display thinking—they help organize and refine students' reasoning as well. Face-to-face tools include small-group models, whole-group consensus models, summary tables, routines for revising models, lists for competing hypotheses, and explanation checklists. These may be unfamiliar to you now, but we provide many examples in each chapter and describe how they are used to best effect.
- *Scaffolds for talk, listening, and writing* can take the form of sentence frames to start conversations, norms for whole-class discussion that are developed

by students, roles that students can take up in small-group activity, structured ways to get students to listen actively to one another, and guides for how to help students rehearse final explanations or arguments. Scaffolding is a term used a lot in education but is poorly understood, so we define it and provide many examples of how it is used during AST.

- *Tools for improving teaching* include guides for deciding what you and your colleagues want to change and how to get started. We also share instruments for collecting data on participation from students and displays that can help teachers see data trends in students' progress around science ideas.

Not surprisingly, all of the tools we've just listed work hand-in-hand with the theory of action that goes with AST and in particular with the four sets of core practices. We've seen these tools shape our teachers' vision of what is possible in their classrooms. We've also seen teachers adapt these tools so they function more effectively with different groups of students at varied grade levels.

FINAL THOUGHTS ABOUT RESEARCH-BASED TEACHING

Over the past decade, several authoritative documents have been produced by groups of teacher leaders, scientists, and educational researchers. These have been clear and consistent about the kinds of experiences science learners need.[9] Two products of consensus—a report called *Taking Science to School* and the *Framework for the Next Generation Science Education Standards*—sum up what students (and teachers) should be able to do, from elementary through secondary levels:

- understand, use, and interpret scientific explanations of the natural world
- generate and evaluate scientific evidence and explanations
- understand the nature and development of scientific knowledge
- participate productively in scientific practices and discourse

Most teachers read this list and imagine that they could use some help with one or more of these areas. Indeed, these student competencies are not fostered by common forms of K–12 science instruction in the United States (as underscored by the breakdown of strengths and challenges listed in table 1.1). Large-scale classroom observational studies show that many teachers create dynamic and challenging lessons, but the broad trends indicate that most

TABLE 1.1. **Strengths and challenges of American K-12 science instruction**

RELATIVE STRENGTHS OF TEACHING	SERIOUS STRUGGLES
Lessons generally well-organized	Content presented as facts, definitions, algorithms, procedures
Clear learning goals	Questioning does not stimulate thinking, discourse is teacher-centered
Frequent, high-interest activity	Few connections made between activity and big science ideas
General respect for students' ideas	Student ideas or everyday experiences not used as resources

lessons focus on activity rather than sense-making discourse.[10] In addition, pressing for "why" explanations is exceedingly rare, questioning in general is among the weakest elements of instruction, and less than a third of lessons take into account students' prior knowledge.

International tests (such as the PISA studies) show that US science students struggle with interpreting scientific evidence, identifying assumptions behind knowledge claims, using evidence, understanding the reasoning behind conclusions, and applying knowledge of science to new situations.[11] These research studies tell us that as a nation we are not meeting our teaching goals, but they don't tell us *how to change our practice* so that we can achieve desirable outcomes for all students. There is research that can help shape teaching practice, but, as we have described, the translation to practice is problematic. No single research investigation definitively tells us "This is how you should teach." For example, there is convincing evidence that having students develop coherent and accurate scientific explanations for themselves, rather than being provided with these explanations, results in deeper and more integrated understandings of the subject matter. On the other hand, there are also research studies showing that judicious use of direct instruction is valuable in helping some students develop coherent scientific explanations. It turns out that powerful teaching combines direct instruction with extended opportunities for students to make sense of explanations on their own terms.

These studies never point to a right way to teach; they can only tell us that under certain instructional conditions, certain versions of instructional practice are more influential than others for particular kinds of student participation and outcomes. This is why—even with access to research findings on strategies like group work, formative assessment, and various inquiry approaches—the professional science teacher must still exercise judgment about every dimension of his or her practice every day, and not chase after simple formulas for success offered at one-day workshops. In this book we provide you with understandable interpretations of research that can help inform your everyday decisions.

When we use our core practices and tools with teachers, some of them ask a very fair question: Isn't following research-based curricula good enough? Why would we reinvent what experts have determined works? We are very clear in our response: While there are good materials out there on the market, professionals can never place their faith in the notion that the curriculum is the one tool—the Swiss army knife of the profession—that will do all sorts of decision making for them. Only a small number of curricula that use the label "research based" have actually documented what students have learned from the activities and made changes in the materials based on those evaluations.

Even if you have an excellent curriculum, it is a mistake to imagine that it does the work of organizing how you should teach your students. What teachers do in the classroom is, in fact, more influential for students' academic futures than any other in-school factor including quality of curricula, type of school, length of school year, or peer influences.[12] Our vast national investments in new standards, curricula, assessments, technology, and professional development translate into student learning only through the many face-to-face encounters that teachers have with students every day, and the decisions made in those moments to press for or retreat from deep understanding, to engage in authentic science activity or prepare for the next high-stakes test, to encourage students' identities as capable knowers of the natural world, or to politely answer all their questions for them. That's a serious responsibility to be placed on our shoulders, but it's one that should motivate us as well.

TWO

CORE PRACTICE SET #1

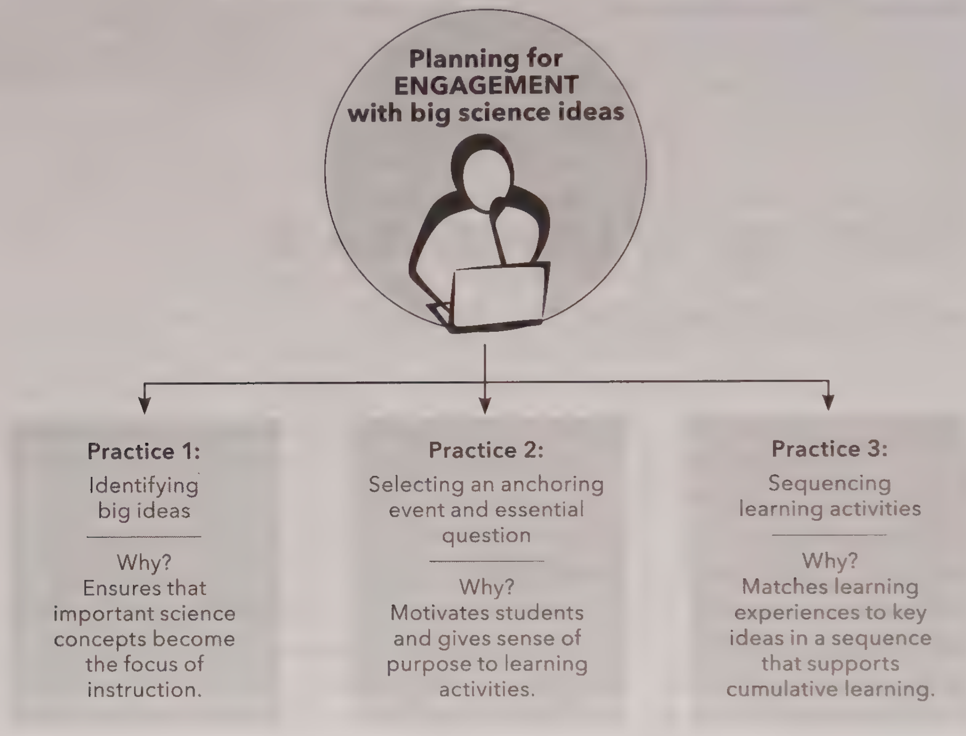
Planning for Engagement with Big Science Ideas

NOT EVERY SCIENCE IDEA in your textbook or curriculum is worth teaching. Instructional materials often contain a sprawl of science ideas that don't cohere into a bigger picture for learners; they call for far more activities than teachers could reasonably do with students, and in the process, inject unnecessary technical vocabulary.[1] As a result, students can experience instruction as a series of unrelated lessons. They may not understand how readings or new concepts fit together to create usable knowledge for figuring out problems in the world. Without a focus on big ideas, the goals of hands-on work can also be puzzling for students. When asked why they are using materials and equipment, they often say, "Because the teacher wants me to," or "We do labs on Wednesdays."

There are solutions for these issues. In this chapter we'll describe a unit planning process in which you start by identifying the most important science concepts in your curriculum and standards, and leave out trivia so that your students spend more time building knowledge about powerful ideas. We'll then show you how to identify complex and puzzling events that both embody these science ideas and interest students. These events can anchor their efforts to understand core disciplinary concepts in meaningful ways.

This set of planning practices, illustrated in figure 2.1, is a systematic design process guided by clear learning objectives for students. The overarching goal is to construct or modify a series of lessons that help students build knowledge

FIGURE 2.1 **Core practices: Set 1**



in coherent and cumulative ways. This unit planning process puts challenges on the horizon that students care about. To be clear, when we refer to a "unit" we mean between three to four weeks of instruction; this is the time scale on which teachers can most easily see changes in student understanding.

The three planning practices that make up this set are as follows:

- identifying a group of science ideas that are fundamental to explaining most phenomena related to the topic that students will be studying
- selecting an anchoring event and essential question that will support sustained intellectual challenges for students over the course of a unit
- sequencing learning activities in ways that help students build cumulative and coherent knowledge over time

PRACTICE 1: IDENTIFYING BIG IDEAS

Science topics such as earthquakes, solubility, or cellular respiration are starting places for unit design. Unpacking these topics begins with a look at the standards and at your curriculum materials. Whatever standards you use will likely have statements about what students should know and be able to do. Whatever curriculum you use will likely have key ideas printed in bold or used as chapter titles or section headings. Many teachers, however, tell us they don't have an official curriculum, or that they are expected to invent it themselves; in these cases, they look primarily in the standards for their big ideas. The core practice here is to identify the big ideas in the curriculum and/or standards that relate to the topic students will be studying.

The next move is to identify how these ideas might be related to one another and which are *most* important to teach. You'll prioritize two or three of the most powerful ideas to focus the unit on, then identify a second tier of ideas that support the development of those core ideas, and finally discard many ideas that would be nice for students to know but would likely detract from their efforts to deeply understand the concepts you've marked as most important. The routine we use to coordinate this work has been referred to as the *whiteboard activity*, and it is best done, of course, with colleagues.

The Whiteboard Activity Step-by-Step

Identifying ideas in standards and curriculum

Start by looking at the standards you are responsible for. Identify those that relate to your topic and write each on a sticky note. In figure 2.2, across the top of the whiteboard, we show four standards that a group of middle school teachers identified as being relevant to a unit on earthquakes they were about to teach. Next, take a look at your curriculum (if you have one). As you page through it, note the most prominent ideas that are mentioned. These are often printed in bold or used as headings in the teacher's guide. Select up to five of these ideas—more than five is likely too big a chunk to explore in depth—and write each on a sticky note. The bottom row in figure 2.2 shows ideas from the middle school earthquake curriculum. If you have no curriculum, you should select six or so ideas from the standards.

We've learned that teachers find it difficult to do this work unless they have "cheated a bit" and started to identify a tentative anchoring event that relates to the topic. You do not have to decide on the perfect anchoring event at this point in the process; just a rough idea is enough, and you can even keep two or three possibilities in mind if you like. Write out one sentence that describes your anchoring event(s), then get back to the sticky notes.

Clustering ideas that are related

Now start playing with different arrangements of the sticky notes—representing how the ideas are related to one another. You can do this by placing some closer to others, or you can use other strategies that make more sense to you. Most of our teachers prefer to move the more central ideas closer to the center of the whiteboard, and the tangential ideas to the periphery. Take at least twenty minutes to sort and re-sort, thinking out loud with your colleagues until your arrangement is somewhat stable. Even as you move these sticky notes around, bear in mind that ideas from the standards have to be given priority—you can't just leave them on the margins.

Identifying ideas with the power to explain

Now you'll need to determine which two or three ideas have the greatest explanatory power. To do so, ask yourselves the following: Which of these ideas, if our students could really understand them deeply, would help them explain a range of other ideas in this unit? In our example with the earthquake unit, the teachers initially put at the center of the whiteboard "Convection drives plate movement, uneven heating from the core." But it was unclear what they thought was really important about this. We urged them to write the idea out in a full sentence (this is difficult). They struggled for about ten minutes, then wrote: "Motions of the mantle and its plates occur primarily through thermal convection—the cycling of matter due to outward flow of [heat] energy from earth's interior and grav mov't [gravitational movement] of denser materials inward." This is a much clearer expression of a big idea (figure 2.2). It also fits nicely with three criteria, in the form of questions, that we developed for big ideas:

- *Can this idea help explain a range of other ideas in the unit?* Yes, in our preceding example it helps explain seafloor spreading, earthquakes, some of mountain building, and where the long-term heat source in the earth comes from.
- *Does this idea express relationships, not just facts?* Yes, it expresses links between heat and buoyancy of the mantle material, between movement of mantle materials and plate movement.

FIGURE 2.2 **Construction of "big ideas" about earthquakes from collaborative whiteboard activity**

FROM STANDARDS	Hot, solid inner core. Liquid outer core. Solid mantle and solid crust.	Plate tectonics and large-scale system interactions.	Waves generated by earthquakes have properties which determine ability to move through earth and cause damage.	Natural hazards and other geologic events have significantly shaped the course of human history.
BIG IDEAS	Depending on the density of the plates making up the crust of the earth, their interactions cause e-quakes, mountain building, and mid-ocean ridges.		Motions of mantle and its plates occur through thermal convection—cycling of matter due to outward flow of [heat] energy from earth's interior and grav mov't of denser materials inward.	
FROM CURRICULUM	Plates can move along fault lines as a result of built-up stress.	Earth shaking P-waves S-waves Aftershocks	Using earthquakes to get evidence about the earth's interior.	Measuring earthquakes: Richter and Mercalli scales.

- ✓ *Is this idea written as a full sentence so we are clear with one another about what it entails?* Yes, the original phrase "uneven heating from the core" was unpacked in more detail.

After a few minutes, these teachers had a second big idea: "Plate tectonics can be viewed as the surface expression of mantle convection." They felt, however, that this needed more refinement because it did not meet the first of our three criteria, and it seems to just repeat the other big idea. They changed it to: "Depending on the density of the plates making up the crust of the earth, their interactions cause e-quakes, mountain building, and mid-ocean ridges." They had an "a-ha" moment, and we agreed that they had landed on the second of two powerful ideas.

Challenges That Pop Up During the Whiteboard Activity

Two challenges may arise during this routine, both of which can be generative for your thinking. One is that you may realize the biggest idea is *not actually on any of your sticky notes*, meaning that it is not named in your standards or curriculum. This happens more often than you might think. If this is the case, then you have to insert the core concepts yourselves. Here's an example. A group of eighth-grade teachers was planning a unit on phase changes in matter. They got stuck because ideas from their curriculum, like melting point or states of matter, couldn't be used in any clear way to explain other ideas, nor could they explain phenomena in the real world. But then we asked the teachers if there was some idea that was more fundamental, something underlying these other ideas. After a few minutes they started to realize that both melting point and states of matter could be explained by the making and breaking of intermolecular bonds. So, they got out another sticky note, put that idea in sentence form, and placed it in the middle of the whiteboard.

The second challenge, also productive, is that you realize the most important ideas are not found on any one note, but rather in *the relationship between the ideas on two or three notes*. In our phase change unit example, after a bit more discussion the teachers asked themselves, "What makes the bonds break?" It's kinetic molecular movement—a kind of energy associated with heat. They got another sticky note out and wrote "kinetic molecular energy," putting it right next to the "making and breaking intermolecular bonds" note. This pair of ideas, then—or, more precisely, the relationship between them—could help explain nearly everything in the unit. They later combined these two ideas into a single sentence, which helped them clarify as a group what the relationships were.

This is not a process that you should feel closure on in just an hour or so. It's messier than we've described. Most teachers work on this with peers for a while, then come back a day or two later with fresh insights they had while riding the bus, doing the dishes, or taking a walk. This is simply part of the same creative process that other professionals like artists, architects, and engineers use to break down and reassemble ideas for a purpose. One group of teachers expressed their experience this way: "It was really hard, but worth it in the end."

PRACTICE 2: SELECTING AN ANCHORING EVENT AND ESSENTIAL QUESTION

The selection of anchoring events happens in the middle of the planning process, but before we go into the guidelines for doing that, we want to introduce some background to help you understand what the larger planning process is building toward and why anchoring events provide unique opportunities for students to learn content in cumulative and compelling ways.

Why We Focus on Action in the World

The term *anchoring event* is shorthand for any complex phenomenon for which students can develop models and explanations over the course of a unit. Examples include solar eclipses, the human body maintaining its internal temperature in extreme environments, the spread of invasive species in an ecosystem, or cars crumpling in crash tests. Anchoring events can have historical significance, such as the survival of particular species of finches on the Galapagos Islands. They can be about issues of social justice, such as the rise of diabetes or asthma among adolescents who live in poverty-impacted communities. They can be about epic phenomena like tsunamis or everyday occurrences like the spread of smells through the air.

We will use terms like *events*, *processes*, and *phenomena* in this chapter just for the sake of variety, but we don't want to confuse you. Events usually take place in a short time span (solar eclipses, crash tests for cars), while processes usually take place over longer periods (repair of tissues in the body, natural selection). Events and processes both fall under the larger category of *phenomena*, or in other words, "things that happen." There are no hard-and-fast rules for when to use one term versus another.

What all good anchoring events have in common is that they motivate students to try to explain what is going on. These explanations are elaborated and evidence-based accounts—ones that require young learners to draw upon a wide range of science concepts and to engage in multiple investigations in order to construct narratives and representations for the target phenomenon. The process of scientific modeling, which we explore more deeply in upcoming chapters, is a companion disciplinary practice to explanation. Modeling has many benefits for learning, but its most powerful feature is that it makes student thinking more visible, and in different ways than the written or spoken word.

Anchoring events are precious commodities in AST networks: when teachers develop good ones, those events are adopted by others very quickly, becoming modified and improved over time. That being said, we want to make clear that anchoring events cannot be the basis for *all* learning in a unit of instruction. No event or process can embody every single science idea worth teaching. There will be days when you have to explore concepts that may be only tangentially related to the anchoring event you've chosen, but these days are the exception rather than the rule. An anchoring event and its essential question, then, are not the only things learners study during a unit, but they do represent the focus of students' ongoing attempts to build knowledge, individually and together as a class.

The Emphasis on "Why" in Explanations for Anchoring Events

In AST, developing causal explanations and models becomes a centerpiece of classroom activity. This is because constructing explanations for natural events is at the core of what scientists do. But it is also because this is the most demanding kind of intellectual work you can ask students to engage in. They have to link many science ideas together and understand how evidence might support different parts of their explanations. The development of these types of explanations and models takes many days, or even weeks, of steady construction and regular revisions.

Causal explanations and models are not assembled simply to describe in detail what happens during an event or process, but rather to account for why the phenomenon unfolded over time the way it did. The "why" in most of these explanations almost always involves things and actions that are *not directly observable*. This cast of unseen characters, things, and events influences the phenomenon (what we can observe) in some way. These components may not be directly observable for several reasons: they may work at such a small scale (atomic bonding or genetic recombination); they happen so quickly (electricity moving through a circuit) or over long time spans (evolution, glaciation, formation of solar system); they are inaccessible to direct observations or measuring instruments (events in the interior of the earth, neurons firing in the brain); they are abstract (unbalanced forces, concentration gradients, alleles); or, very likely, they are some combination of these. In upcoming chapters you'll see specific examples of how such unobservables are used by students to explore what is observable.

This simple relationship (using unobservables to explain the observable) has worked for our network of teachers at every grade level and in all science domains. It also happens to be the basis of authentic science explanations and arguments. To help you differentiate between levels of explanation, we've included appendix D to show contrasts between "what," "how," and "why" accounts by students. Some teachers write out explanations at each of these levels for the focal event of the unit, so that they can better plan for supporting students to reach the "why."

Why We Focus on Anchoring Events and Not Just Topics

Units built around anchoring events are very different from a set of lessons assembled around topics or themes. Topics are like chapter headings in textbooks—ecosystems, chemical reactions, plate tectonics, and so on. These are, of course, legitimate starting points for planning; however, when teachers use topics as the only organizing frame for unit development, they are free to put anything and everything into the curriculum. While all lessons in a unit might be nominally related to a topic (e.g., cells, or force and motion), it's usually only the teacher who sees how the activities and readings hang together. Students, on the other hand, are left to guess what all the activities, taken as a whole, are supposed to mean. The same principle applies to instruction based on themes such as "art in science" or "building a future with sustainable resources." These units are often a collection of activities that are related only in name to a bigger set of ideas. We are not against the teaching of innovative and dynamic material, but we do recommend that it is addressed in the context of explaining anchoring events or projects in which students design some authentic product. These tie lessons together and consolidate student learning of important ideas as units progress.

The research literature on learning is clear that students develop deep understandings best from being engaged with complex problems. This is not a "basics first" approach in which students learn disconnected facts, vocabulary, and formulas before doing any meaningful work. Rather, it is *within the quest to understand complex problems* that facts, terminology, concepts, mathematical equations, and lab skills become useful to students. This is true for everyone in the classroom, but in particular for English language learners, who depend upon the context provided by well-chosen phenomena in order to make sense of the words being used and the science activity as well.

Picking Back Up with the Planning Process

So far in your planning process you have selected a subset of science ideas from your curriculum and standards that are important to teach, and identified two or three of these as core to the unit you'll design. You have also moved other science ideas and vocabulary "off the table." Now, with the most important targets in mind, you will make the final decisions about a compelling science event for which your students can create evidence-based explanations and models over the course of a unit.

Anchoring events are phenomena rather than topics or questions

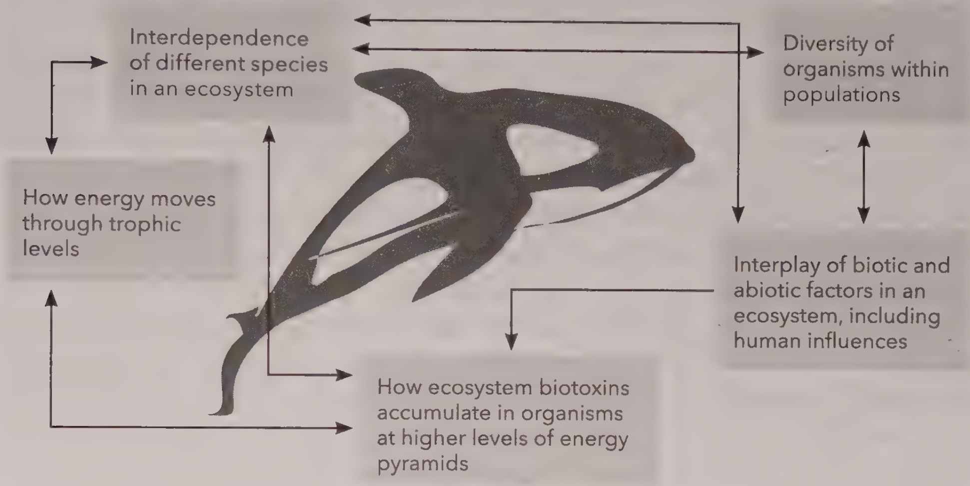
Anchoring events are characterized by a set of circumstances that unfold over time in particular ways. This is what makes them different from curriculum topics or themes. Is chemical change a phenomenon? No, it is more like a topic. On the other hand, your bicycle rusting in the back yard is a phenomenon—it takes place over time, and has a beginning, middle, and end. Knowing the parts of the cell and what they do is a set of facts, but the uncontrolled spread of cells within a body (cancer) is a phenomenon.

Explanations for anchoring events require students to integrate a number of important science ideas together

In a high school unit on ecosystems in Washington State, several of our teachers have focused students on the puzzle of why killer whale populations are declining in Puget Sound. There are several viable explanations for this phenomenon, but they all require that students understand the ideas shown in figure 2.3, and how they work together. We chose this example because it illustrates the principle that understanding any one important science idea requires that students see how it can be used *with* other concepts to make meaning of complex events and processes.

The integration of a number of such ideas into explanations is what makes some anchoring events more rigorous than others. This idea applies to any grade level. As we mentioned in chapter 1, one of our kindergarten teachers had her students explore the question "How can somebody little bump somebody big off the end of a playground slide?" Students' explanations and models at the end of the unit incorporated the ideas of friction, gravity, forces as pushes

FIGURE 2.3 **Ideas that students must integrate to explain the decline in orca populations**



or pulls, and the relationships between a person's position on a slide and the energy released in a collision at the bottom.

Anchoring events are more compelling to students and more complex to explain if they are context-rich

Context-rich anchoring events are about a *specific* event that happens under *specific* conditions. So the question for teachers is how to transform the phenomenon from a generic science idea into a context-rich case with details. Can earthquakes, for example, be about the case of a particular pattern of earthquakes in a unique geographic region? Or perhaps a comparison between two earthquakes of equal magnitude that resulted in differing amounts of damage in two specific areas because of where the focus was located? Can cellular respiration be about a young person who has been hospitalized because a dietary supplement she uses has interfered with her ability to metabolize glucose? The details—which often include real people, places, and situations—make these stories compelling to students. The details also matter for how students put the explanations together; in the dietary supplements example, they wanted to know if the person had been taking these pills for a long time, how old she is, and if the damage is reversible. The story is true, unfortunately, and many similar narratives are available online as cautionary tales for adolescents about what *not* to put in one's body.

Occasionally our colleagues have "concocted" anchoring events rather than finding them in the world. In the eighth-grade physical science unit on phase change, one of our teachers had students observe the distillation of a soft drink on the first day. A flask was partially filled with a brand of soda that the students had selected for this demonstration. The teacher heated the soda and, over the course of the class period, steam appeared in the flask and traveled through a tube to a second flask to then condense into a clear liquid. Throughout this unit the students tried to incorporate many of the event's details into their reasoning about why an apparently homogeneous substance (soda) can be separated out in this way, and tried to figure out the role that energy could play in their explanations and models. These details included the brand of soft drink and what its ingredients were, the length of time it took for the distillation to be completed, the length of tube connecting the two flasks, the shape of the flasks, and the fact that a stopper on one of the flasks had popped off twice during the demo. These specifics are precisely what make the anchoring events interesting to students. Some of these details mattered to the explanation and some didn't, but this is another positive thing about anchoring events: students learn to discern what information is useful to their knowledge building versus what information is simply a distraction.

Good anchoring events allow students to construct different types of explanations and models

We don't want students to reproduce the explanations of others. In the soft drink distillation example, some students focused on increases or decreases in the kinetic energy of the molecules during their trip through the apparatus. Others oriented their explanations around the mutual attraction of the water molecules because of their polar structure, and others foregrounded the compounds that were dissolved in the soft drink. Students' accounts varied according to what part of the phenomenon they saw as anchoring their sense making. Students were held accountable for all aspects of the science, but they were allowed to show what they knew in ways that made sense to them. As you read upcoming chapters you'll notice this theme—students can express their understandings in many legitimate ways, and you will want to set up the conditions for them to do this.

Whenever possible, make anchoring events or situations relatable to students' interests

Tying anchoring events to students' interests increases the probability not only that students will be motivated to learn, but also that they will capitalize on their background knowledge and everyday experiences to develop explanations.[2] The most relevant context for study would be some aspect of students' lived experiences (i.e., relating to students' home, school, peer culture, or out-of-school experiences). The second most relevant context is the local community, physical surroundings, or history of a region where students live. The third most relevant context may not currently be connected to students' worlds but could be important to their lives or careers beyond school. All three levels of context are important and should be considered when you are selecting an anchoring event.

When you start working on anchoring events, you'll reach the limit of your own subject matter understanding very quickly. You should begin looking at various resources on the web or in texts to expand what you know about the topic. As professionals, we can never assume that we know enough about the subject. It is important also to work with your colleagues, asking them how they understand the explanations, models, and other ideas related to the topic in the curriculum.

Developing Essential Questions to Go with Your Anchoring Events

A good anchoring event is made even more effective when it is accompanied by a compelling essential question (also known as a *driving question*). An essential question cannot be answered with a yes/no response; it requires critical thinking. A sample essential question for a unit on cells in biology might be "What makes wounds heal in different ways?" For a unit on the respiratory system, an essential question might be "Why is asthma so prevalent in poor urban communities?" For a unit on oxidation in chemistry, an example might be "What keeps things from rusting, and why?" For a unit on forces in physical science, an example might be "How does this pulley system help me lift things that are heavier than I am?"

In a middle school unit on earth-moon-sun interactions, one of our teacher colleagues had planned for the essential question to be simply "Why do solar eclipses happen?" Her own students, however, began talking about more interesting questions, some derived from their own families' experiences. These became the focus of the unit: "Why are solar eclipses so rare and so predictable?" The students' questions are better because they'll take them beyond understanding why these events occur (which students could look up in a lot of places) to understanding how gravity has kept the earth, moon, and sun tied together in regular patterns of movement over millions of years, and the different ways that the moon's shadow can cross the earth's surface. Here's another case we briefly mentioned in chapter 1: In preparing for a high school biology unit on population dynamics in ecosystems, a group of teachers decided to use the reintroduction of wolves to Yellowstone National Park as the anchoring event. The original essential question was "How could the reintroduced wolves cause so many changes in the ecosystem?" But the teachers did not think this would compel students to include in their explanations how the social behavior of animals like wolves can result in sweeping changes to the behavior and survivability of other populations. So they suggested a small change that made a big difference in what was expected in students' explanations: "How can *so few* wolves cause so many changes in the ecosystem?"

Some essential questions, like the ecosystem example, require students to explain the anchoring event. In other cases, such as with the solar eclipse, the final pair of essential questions (why so rare and so predictable) does not specifically require students to explain why the phenomenon occurs. If this latter situation is the case in your unit, you should make it clear that students will indeed be responsible for producing explanations and models for the event, perhaps doing this "on the way" to answering the essential question(s). Essential questions, no matter how interesting, should never excuse students from developing evidence-based causal accounts for the anchoring event.

PRACTICE 3: SEQUENCING LEARNING ACTIVITIES THAT BUILD SPECIFIC UNDERSTANDINGS

In this final planning practice, you select and arrange learning activities for your students that will help them wrestle with the big ideas of your unit. You begin this by outlining an explanation for your anchoring event. Include unobservable events and processes to form the explanation. This should be *gapless*, meaning that it includes necessary details and does not leave out any links between causes and effects. It should be written as "just beyond" what students at your grade level might be capable of. You are not aiming for them to reproduce your explanation. Rather, one purpose of writing it is to prime you to be responsive to the prior knowledge and out-of-school experiences students draw upon that might be relevant to the explanation. You'll be surprised how well your preparation works when eliciting students' ideas at the beginning of the unit.

There's a second reason to write an explanation yourself. If it incorporates most of the important science ideas related to the overall topic (as it should), then you can use it to identify activities, investigations, readings, and types of conversations that should make up the unit. For example, in chapter 1 we mentioned a group of fifth graders trying to explain how a singer could break a glass with just the energy from his voice (we've had versions of this unit taught at third, fifth, and ninth grade). Figure 2.4 shows the fifth-grade teacher's explanation, with distinct science ideas indicated by a black bar in the left margin. Each of these was matched up with one or more learning experiences for students. Some of these came from the curriculum, while some had to be added from other sources.

Once you've selected the learning experiences, you can start arranging these in a sequence that makes sense for students. In our work with teachers we do not try to agonize over a perfect sequence, so we ask ourselves a simpler question: If we divided the unit into three parts, then which activities, readings, investigations, and so on, should go in the first third, middle third, and final third? In doing this "roughing out" we have three rules of thumb that are used together. The first is that ideas from the explanation that are more directly linked to students' prior knowledge or everyday experiences should go earlier in the unit. In contrast, ideas that are abstract or purely conceptual can be introduced later and build upon the more concrete ideas introduced earlier. The second rule (which can be used with or in place of the first one) recognizes that some ideas are built from other ideas—they are like composites. These we put later in the unit, and we put the more elemental ideas that make up these composites earlier in the unit. In the sound energy example, resonance is a complex idea that requires students to understand more elemental concepts—like sound as vibrations, sound as waves, and frequency as a quality of waves—so it would not be introduced early in the unit. The third rule is that most events or processes have a beginning, middle, and end, chronologically speaking (in

FIGURE 2.4 **Sequencing activities (on left) that match up with the explanation for the singer shattering the glass (on right)**

Arrows indicate only a sample of the connections.

Making and sensing sounds in the body

1. Vocal cord and eardrum readings—How do we make sound when we talk and sing? What parts of our body help us make loud sounds (vocal cords, diaphragm)? How do we hear sounds?

Travels through a medium

2. Recess ball bounce observations—Sound of bouncing ball travels in all directions, can feel vibrations in floor, echo off walls; volume decreases with distance.

Vibrations

3. Tuning fork vibration exploration—How does force relate to volume? How does size relate to pitch? How does a tuning fork make sound?

Energy

4. "Sound is energy"—The force of sound; What does "volume" mean?

Distance

5. Sound in the ground—Listening through tables, doors, and floor for sound. How does sound travel?
6. Hallway investigation—Volume of sound decreases over distance.

Resonance

7. Hum drum activity—Bowl begins to resonate by humming, vibrating bowl makes salt "dance" that is different motion than blowing salt (wind moving air vs. vibration of air).
8. Grandpa John resonating tuning forks video clip—Demonstrates how one tuning fork can vibrate a "twin" fork across a distance without touching (resonance).

Amended notes after teaching:

9. We did not plan to go into the level of molecule movement. However, students brought up the idea of particles so some small group discussions focused on the idea of particles.

Sound energy is closely related to mechanical energy. When an object vibrates, such as vocal cords, the vibrations push the surrounding molecules in every direction (4). A medium is necessary for sound energy to be moved from one place to another because the sound travels by pushing molecules into each other in all directions emanating from the source, like dominoes (2 and 5). A medium is composed of molecules and can be solid, liquid, or gas.

Each sound has properties like frequency and volume. Higher pitch sounds have higher frequency. This means that the vibration is pushing surrounding molecules in pulses at a high rate over time. If it also has high volume, then the vibration pushes the molecules harder at that rate. For low pitch, the sound wave has lower frequency. This means that the vibration is moving molecules at a slower rate (more time between pushes). Again, more volume is a push with more energy and the vibration will be larger, but the rate of vibration will stay the same if it is the same pitch (6 and 4).

The singer uses muscles to make his vocal cords vibrate (1). The vibrating vocal cords push air molecules that are all around us and inside our trachea and lungs. The push is not constant, but a pulsing compression wave (3). These vibrations travel through air. Air molecules do not move across space but rather they push against neighboring air molecules. This domino effect eventually pushes air molecules into our ears (2 and 5).

We hear these vibrations as sound. Our eardrums vibrate at the same rate as the original vibration so we can hear (and feel if loud enough) him singing the note (1). When the singer hits the particular note, the wine glass begins to vibrate, too (3). The singer listens to hear if the glass is making noise, too (resonating). You can find this note by tapping the glass or running your finger around the edge.

The closer the singer is to this pitch, the more the glass vibrates (7 and 8). Then, as the singer increases his volume on that same pitch, the wine glass really vibrates (6). The glass is flexing and wobbling. Air molecules are always bumping against the inside and outside of the glass. The glass flexes because air molecules bump into the outside of it with more force than usual (extra force comes from sound wave).

The glass will stay together through a little bit of wobbling, but over time the flexing back and forth will break the glass (9). So the shape of the glass is important. The wine glass is thin and round. The tiny stem does not absorb a lot of the vibrations. A thicker glass could absorb the sound vibrations and would not wobble or flex as much, so it wouldn't break (2 and 5). The glass also has to be empty (9). The empty glass will flex and wobble at a certain pitch (7 and 8). However if there were water in the glass, the water would help the glass keep its shape. The water would push on the sides of the glass and keep them from wobbling or breaking. The sound would travel through the water, too (9).

contrast, some are cyclic or are multiple events happening simultaneously), so it is helpful for students to understand the science behind the beginning stages of an event or process first, then explore other ideas later. Now that we've said there are three rules, we should probably add a fourth: none of the first three rules takes precedence over the others. You just have to use your judgment about when to apply them.

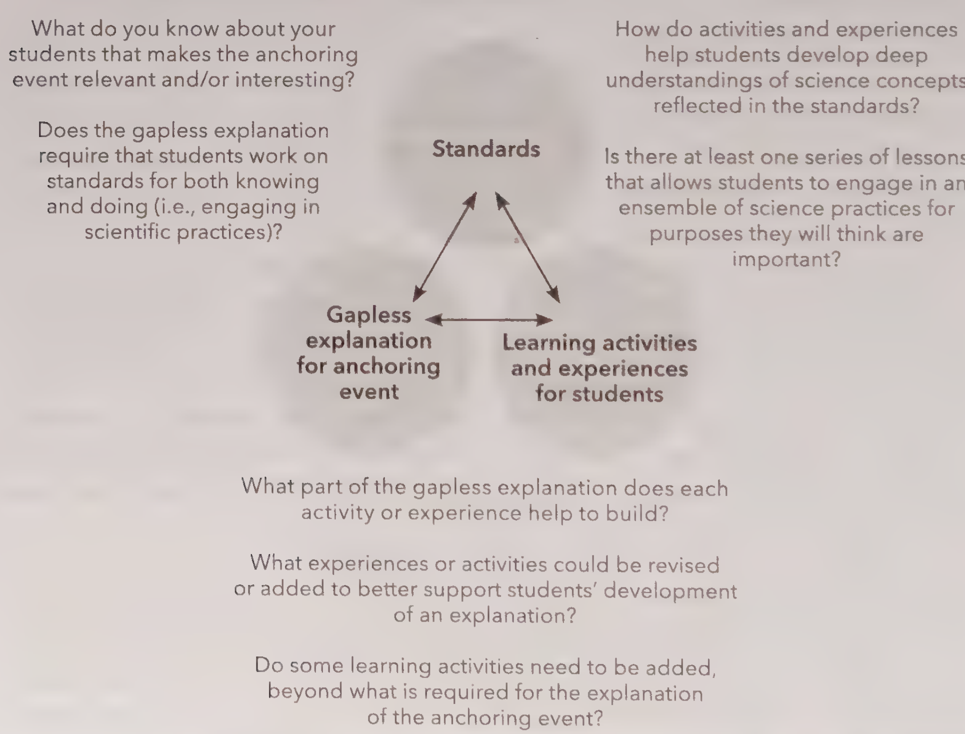
The left side of figure 2.4 shows the list of activities and readings for the shattering glass and how they are matched up with the elements of the full explanation. The teacher used a combination of the first and second rules we just outlined. She wanted to start with activities that were close to students' personal experiences, so, for example, she put a vocal cord/eardrum lesson first. In the middle of the unit students applied ideas about vibration to new situations—tuning forks, sound energy dissipating over distance, and using different media to transmit sound. In the last part of the unit students were asked to use these ideas, together, to understand the complex idea of resonance.

We should add here that by the end of these units, students are expected to do more than construct a linear account of why the glass shattered. In AST, students are helped to understand, in some depth, what each part of their explanations or models means. Students should be able to *expand their explanations* in different places. For example, they should be able to expand on the nature of energy transfer by responding to the questions: Does all the energy end up in the glass? Why or why not? Students should be able to expand the part of the explanation about hearing in humans, describing how people can tell what types of sound are being made by vibrating objects. In the fifth-grade version of this unit, students should be able to expand on the nature of compression waves and sound traveling though media, by explaining how a sound wave is similar or different from a surface wave in a pond. In our ninth-grade version, students have to expand upon why a logarithmic scale is needed to measure sound energy in decibels. Expandable explanations are the result of going in depth on key ideas in your unit, and being purposeful about linking them with other ideas.

Tightening the Triangle

As your planning moves into its final stages, you can do a check on how connected learning activities are with the gapless explanation and the standards that apply to your topic. We show these connections using a triangle, with the vertices each representing planning choices you make. Our teachers have developed a set of questions they ask themselves near the end of the design process (see figure 2.5); this check is referred to as "tightening the triangle." Why do we do this? Back in chapter 1 we listed the seven elements of rigorous and equitable teaching, the first of which is "Teachers anchor students' learning experiences in a complex and puzzling science phenomena." Now we've planned that part. But using an anchoring event is only partially effective for learning; students also have to build ideas about these phenomena cumulatively, over time (another element in our list). This requires close connections between the anchoring event and the sequence of learning activities—connections that become "visible" only when the newly designed unit is examined as a whole. Similarly, it is best to check at this stage if you have plans for helping students use ensembles of scientific practices to make sense of the phenomena (another

FIGURE 2.5 **Questions about connections between three parts of the planning triangle**



of our elements). Because many state and district standards now include student performances like making arguments, carrying out investigations, modeling, analyzing data, and communicating information, it is important to see where you've built in opportunities for students to engage in connected episodes of authentic science work and how these activities build on one another to help them develop new knowledge.

Sometimes disconnects in the triangle are not evident until you teach the lessons, and that can't be helped, but you do want to avoid major issues up front, such as not providing learning experiences that match up with important standards or having students do activities that they don't perceive as helpful in understanding the anchoring event. Keep the triangle tight, and you'll be able to support learning that students recognize as moving them forward on big ideas.

HOW TO GET STARTED WITH COLLEAGUES

We recommend that you and your colleagues devote several meetings during the school year to designing your first unit, or identify time during the summer for this work. If your school allows science teachers to determine how regular professional learning time is used, then you could petition your administrator with a statement of rationale for why this planning project is worthwhile. If you have a district instructional coach, enlist that person to help you. The planning process itself happens in cycles. Each cycle includes setting achievable short-term goals, working together on one of the planning phases described in this chapter, going off and thinking individually for a few days, and then coming back together to compare ideas and make decisions. A total of five or six meetings is a reasonable estimate to develop a unit, and this takes into account the time in between for each of you to learn more about the science content.

You can elect a unit to adapt that you have taught before, one that takes about three to four weeks. Don't feel like you have to reinvent the wheel by creating all new learning activities. Budget a couple of meetings for each of the core planning practices (identifying big ideas, selecting an anchoring event and essential question, and sequencing learning activities). Appoint one member of your group to keep track of documents and other resources that you identify or develop by making them available online. Post pictures of planning products like the results of your whiteboard activity, links to videos that represent potential anchoring events, and explanations for your anchoring event that can be edited by the group.

In the planning process we often see teacher groups stall out over selecting the perfect anchoring event. It's fine to have one that is just "okay." Attend more to identifying the big science ideas and developing a sequence of activities that students will use to create explanations and models over time. One by-product of this planning process is that everyone can see where they need to learn more about the science itself before teaching about complex and contextualized phenomena. For this reason, it helps to establish norms around talking candidly about the gaps you all have in your content knowledge.

Perhaps the best piece of advice we can give is to simply get started. You'll learn best from doing the work, and it gets easier each time you do it. Keep in mind, however, that you cannot convert all your units in a single year. Developing two or three really well-designed units over the course of a year is excellent progress.

THREE

PRODUCTIVE DISCOURSE, PART 1

Talk as a Tool for Learning

MOST STUDENTS ALREADY EXCEL at talk. They can exchange words with others to express how they are feeling at the moment, to get questions answered, or to make plans for later in the day. But unlike conversations in their everyday life, discourse in science classrooms can feel strange. There, students are asked to *compare* different science explanations, *argue* with evidence, *critique* a model, or *unpack* a claim. They are expected to take up technical vocabulary and to follow rules for participation that aren't always clear. Students wonder: *What am I supposed to say? Am I using this word correctly? Is it okay to disagree or ask a question?* They can feel stuck in the middle of unnatural discussions, and the situation can be especially awkward for learners from nondominant backgrounds or those who speak English as a second language. For these reasons, teachers who want to cultivate productive academic discourse—with *all* their students—have to design regular opportunities for them to try out new ways with words, and support them throughout the process of learning to "talk science."

Fostering students' discourse is important because goal-directed talk is a chance to think, and thinking is required for higher-order learning. This may seem simplistic, but here's the logic behind it. Taking a turn within a conversation requires that you activate prior knowledge about what's being said by others, organize possible responses that will fit the flow of the dialogue as well as the nature of your audience, and then verbalize your ideas while monitoring and adjusting in real time what you are saying. This stimulates learning because translating ideas into words is not simply the "reporting out" of what is fully formed in one's head. Under the right circumstances it involves reasoning processes that give structure to loosely formed concepts and makes gaps in logic more evident for those doing the talking. In addition, if we consider learning to be not just a personal act, but also a collective endeavor in which students reason together, then talk is important because it transforms an individual's ideas, puzzlements, conjectures, and questions into public resources for others to think with. In this view, students' outside-of-school experiences, intuitive explanations, and even openly stated points of confusion can be productive for advancing a group's state of understanding. For teachers, orchestrating these types of knowledge-building opportunities requires an uncommon skill set, but one that can be developed over time.

In this chapter and the next, we will share strategies and tools to help you and your students engage in productive discourse about science. The first of these is *prethinking the goals for different kinds of classroom conversations*. Every conversation should have a purpose that students can understand, and if you define this for yourself ahead of time, then it becomes easier to plan how to initiate the talk with students, select tools and routines that can support the goals, and manage specific kinds of participation along the way.

The second idea deals with the *cognitive demand* of questions and tasks that set the stage for classroom talk. Some questions, for example, require limited intellectual contributions by students ("What are the planets in our solar system?") while others can be more challenging ("How do Newton's Laws of Gravitation help us explain the movements of the earth, moon, and sun?"). Having the right mix of high- and low-cognitive-demand questions and activities helps encourage rigorous talk, rather than just more talk.

The third idea is about *developing a repertoire of talk moves to serve the goals of a conversation*. It is much easier to manage conversations if you think of them as activities involving specialized turns of talk that are used to prompt thinking or action by others. Moves like pressing, follow-ups, revoicing, and focusing (all explained later) can be used to help young learners reveal more of their thought processes, but also help them interact with one another's ideas and reason scientifically together.

The next chapter on discourse—just to give you a preview—explores ways to support students so they feel capable of participating in science talk and become