HELPING STUDENTS
MAKE SENSE OF THE WORLD

USING

NEXT GENERATION SCIENCE AND ENGINEERING PRACTICES

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Hawker Brownlow
EDUCATION

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1

MOVING BEYOND "KNOWING ABOUT" SCIENCE TO MAKING SENSE OF THE WORLD

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An Introduction to Scientific and Engineering Practices

Sarah is a conscientious teacher. She has been teaching science to middle school students for eight years. During that time, she's gone from being a tentative novice teacher to being a competent veteran. Throughout her career, she's been alternatively frustrated and pleased with her teaching. Sometimes things seem to be going well, and other times she feels she should be able to get more from her students; she wants them to think more deeply and wishes that she had more "Aha!" moments in her class. Sarah uses the district-wide pacing guide and follows the textbook that was adopted by her school several years ago. Of course, she supplements the district materials with things she's found online, gotten from teaching colleagues, and picked up at conferences, but for the most part, she does many of the same activities from one year to the next. Recently, she has begun to hear about changes that may be coming to the science standards in her state. She is at once excited and intimidated by the big changes in science education. The more she hears about these reforms, the more questions she has about what this means for her as a teacher of science.

As Sarah looks over *A Framework for K–12 Science Education* (*Framework;* NRC 2012) and the *Next Generation Science Standards* (*NGSS;* NGSS Lead States 2013) documents, she has a lot of specific questions about what she is reading. She wonders:

- "What is this focus on practices all about?"
- "Is this just a new name for inquiry?"
- "How should my class look different if I am "doing" the *NGSS*?"
- "If I'm pretty happy with what I've been doing, why would I want to take this on?"

> In another school district, Carlos has been teaching third and fourth grades for many years and loves working with his students. He tells great stories, and the students enjoy doing hands-on activities, such as exploring different rocks and taking field trips to the local children's garden. Carlos's state has recently adopted the *NGSS*, and he is wondering what these new standards mean for him:
>
> - "What will I have to do differently?"
> - "How is this different from the hands-on inquiry I do now?"
> - "How will I have time for the *NGSS*? There is already so much to cover with the literacy and math curricula."

Perhaps you can see yourself in Sarah's or Carlos's situation. You may have some of the same questions about the goals of this reform and what it means for you as a teacher of science. This is an exciting time in science education. We have many opportunities before us to make significant and lasting change in the ways we teach science at the K–12 level. But with major change comes some anxiety. We hope this book can begin to answer some of your questions about the reforms found in the *Framework* and the *NGSS.* Even if your state is not adopting the *NGSS*, you and your colleagues can take advantage of the research-based recommendations in the *Framework* for making science learning more meaningful and effective for all students.

The title of this book expresses a major goal of the current science education reform effort: that students make sense of the natural and designed world by engaging in science and engineering practices. To some educators, this may seem like nothing new. For many years, it has been a goal of science reforms to move from students as passive recipients of knowledge to classrooms in which students are active participants in generating knowledge. Since the 1990s, attempts to incorporate inquiry into science classrooms have been a step forward in efforts to accomplish this. Yet, while these efforts have made some inroads, studies of today's U.S. classrooms and curriculum materials show that many of our classrooms do *not* involve students in very sophisticated versions of scientific practice (Banilower et al. 2013). Instead, in many classrooms, students are primarily studying and recounting factual information and definitions provided by textbooks and teachers and reinforced through hands-on activities that may not be linked to advancing students' conceptual ideas and practices.

As a science education community, let's embrace an opportunity to do more. The reform agenda articulated in the *Framework* and the *NGSS* provides a vision and way forward toward making science education inspiring and meaningful. While the *Framework* and standards do not tell us exactly *how* we should teach, they do provide clear direction for what we should be aiming for in our science instruction. They help us see that there are productive ways to integrate the processes of science with the learning of science and help clarify that we should be pushing for outcomes related to what students should be able to do with the knowledge they have developed over time. The *Framework* states that

> *K–12 science and engineering education should focus on a limited number of disciplinary core ideas and crosscutting concepts, be designed so that students continually build on and revise their knowledge and abilities over multiple years, and support the integration of such knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design.* (p. 2)

Even though some of the themes in the *Framework* and the *NGSS* around engaging students in science and engineering may sound familiar, the documents offer new ways to talk about and organize instruction to meet these goals. In this book, we concentrate on one of the key innovations of the *Framework:* a focus on the practices of science and engineering. The editors and contributors to this book have a great deal of experience in working on how to focus our science classrooms on making sense of the world through engaging in the practices of science and engineering. The contributors include science education researchers and teachers who have explored these ideas in their own classrooms. We, along with many other science educators and researchers, have been collectively working on these problems for years preceding the publication of the *Framework* and the *NGSS.* The work of many of the authors within this volume contributed to the vision put forth in the *Framework.* What you read about in these pages are not ivory tower, experimental ideas or the latest fad that some hope will make all the difference. Instead, these are ideas that have been tested and refined in real science classrooms over many years. This book represents a true collaboration between practicing teachers, those in science education, and learning sciences researchers.

From Scientific Inquiry to Practices

The emphasis on science and engineering practices attempts to build on prior reforms and take advantage of what research has revealed about the successes and limitations of inquiry classrooms. We like to think of the focus on practices as a kind of Inquiry 2.0—not a replacement for inquiry but rather a second wave that articulates more clearly what successful inquiry looks like when it results in building scientific knowledge. The configuration of inquiry classrooms typically allows students to explore the relationship between two variables (e.g., how the mass of a toy car affect its velocity going down a ramp), but often this empirical exploration is not taking place in an ongoing process of questioning, developing, and refining explanatory knowledge about the world. Testing and confirming or disconfirming hypotheses is part of science, but these actions become meaningful by being a part of the broader work of building explanatory models and theories.

This attempt to take our ideas of inquiry in science beyond designing investigations and testing hypotheses has led to the fuller articulation of inquiry as the scientific and engineering practices that enable us to investigate and make sense of phenomena in the world by building and applying explanatory models, and by designing solutions for problems. Making sense of the world, or *sense-making* for short, is the fundamental goal of science and should be at the core of what happens in science classrooms.

What is involved in this sense-making? Sense-making, as we are using it here, is the conceptual process in which a learner actively engages with the natural or designed world; wonders about it; and develops, tests, and refines ideas with peers and the teacher. Sense-making is the proactive engagement in understanding the world by generating, using, and extending scientific knowledge within communities. In other words, sense-making is about actively trying to figure out the way the world works (for scientific questions) and exploring how to create or alter things to achieve design goals (for engineering questions).

When student sense-making is the focus of the classroom goals and purposes, it becomes critical to use science and engineering practices to make sense of the world. Science and engineering practices are the way we build, test, refine, and use knowledge either to investigate questions or to solve problems. As defined in the *Framework*, the science and engineering practices are the different parts of the sense-making process. Here are the eight practices identified in the *Framework* and used in the *NGSS:*

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Now that we have listed these practices, we can be a little more specific about how they are designed to flesh out scientific inquiry. The list includes some familiar ideas that are often present in classes attempting inquiry. We usually think of Planning and

Carrying Out Investigations and Analyzing and Interpreting Data as ways to involve students in an inquiry investigation. But the *NGSS* practices move beyond these two practices to include others such as Constructing Explanations (practice 6). As we will see later (in Chapter 10, p. 205), using the practice of explanation requires more than what sometimes happens with hypothesis testing, in which students figure out how two variables are related. The goal of Constructing Explanations is to be able to say *why* something happens. In the process of figuring out why something in the world happens the way it does, students will often have different ideas and will need to evaluate one another's ideas against evidence (practice 7). As students reach consensus through this argumentation, they represent their general account for why something happens as a general model (practice 2). And, of course, this should all be sparked in the classroom from explanatory questions (practice 1) that arise from an attempt to make sense of some data or patterns in the world. We will get to specifics about these practices and consider the engineering aspects in Section 2 of this book. For now, notice that the mix of these practices leads students to develop explanations and models and interact with one another to compare ideas and reach a consensus.

One critical feature of a sense-making classroom is that students are genuinely engaged in science and engineering practices. An observer should be able to walk into a science class on any day and ask a student, "What are you trying to figure out right now?" The intellectual aim of any work in the science class should be clear to everyone. Rather than stating, "We are learning about photosynthesis or plate tectonics," students should be able to say (and believe!), "We're trying to figure out how the tiny seed becomes this huge oak tree" or "We're trying to better understand why volcanoes and earthquakes happen more often in some parts of the world." These examples illustrate how the students are figuring out the world and illustrate a sense-making goal in the classroom.

In addition to these sense-making goals, another critical aspect of engaging successfully in science and engineering practices is related to the classroom. These practices create a need for designing our classrooms as places in which students are working together to share ideas, evaluate competing ideas, critique one another's ideas, and reach consensus as a classroom community. This shift to practices highlights the importance of working with one another to build and debate knowledge, adding social interaction and classroom discourse to what students need to learn as they participate in scientific sense-making. In this way, the practices extend prior visions of inquiry to define processes for building and refining scientific knowledge as a community.