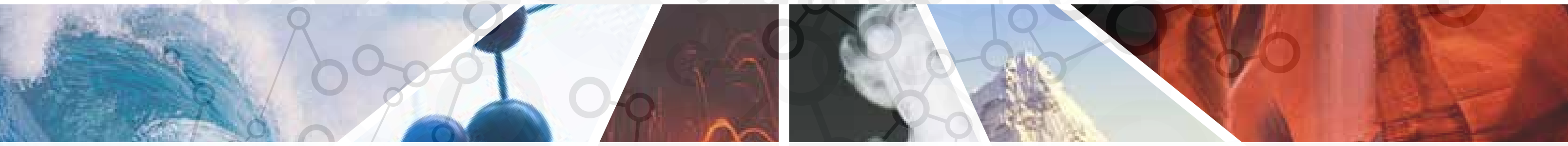
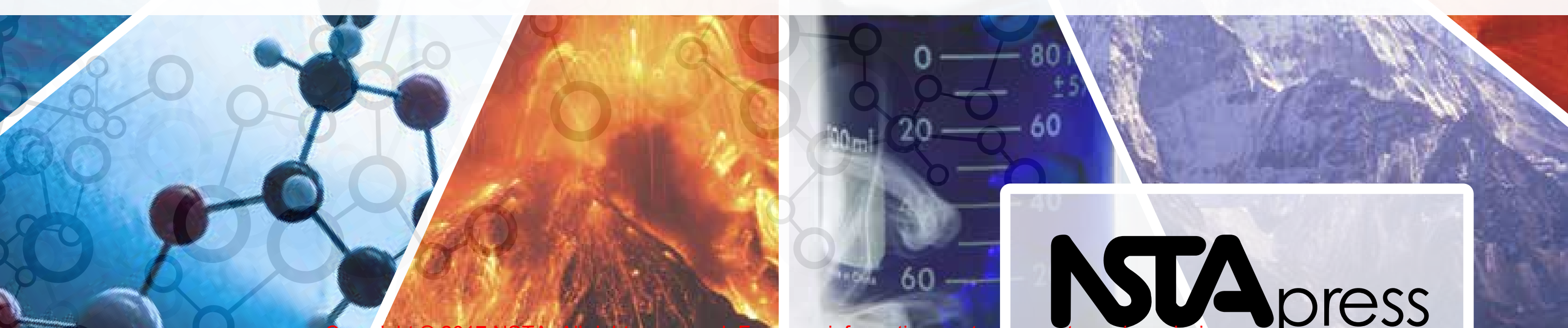
HELPING STUDENTS MAKE SENSE OF THE WORLD USING NEXT GENERATION SCIENCE AND ENGINEERING PRACTICES



Christina V. Schwarz • Cynthia Passmore • Brian J. Reiser
EDITORS



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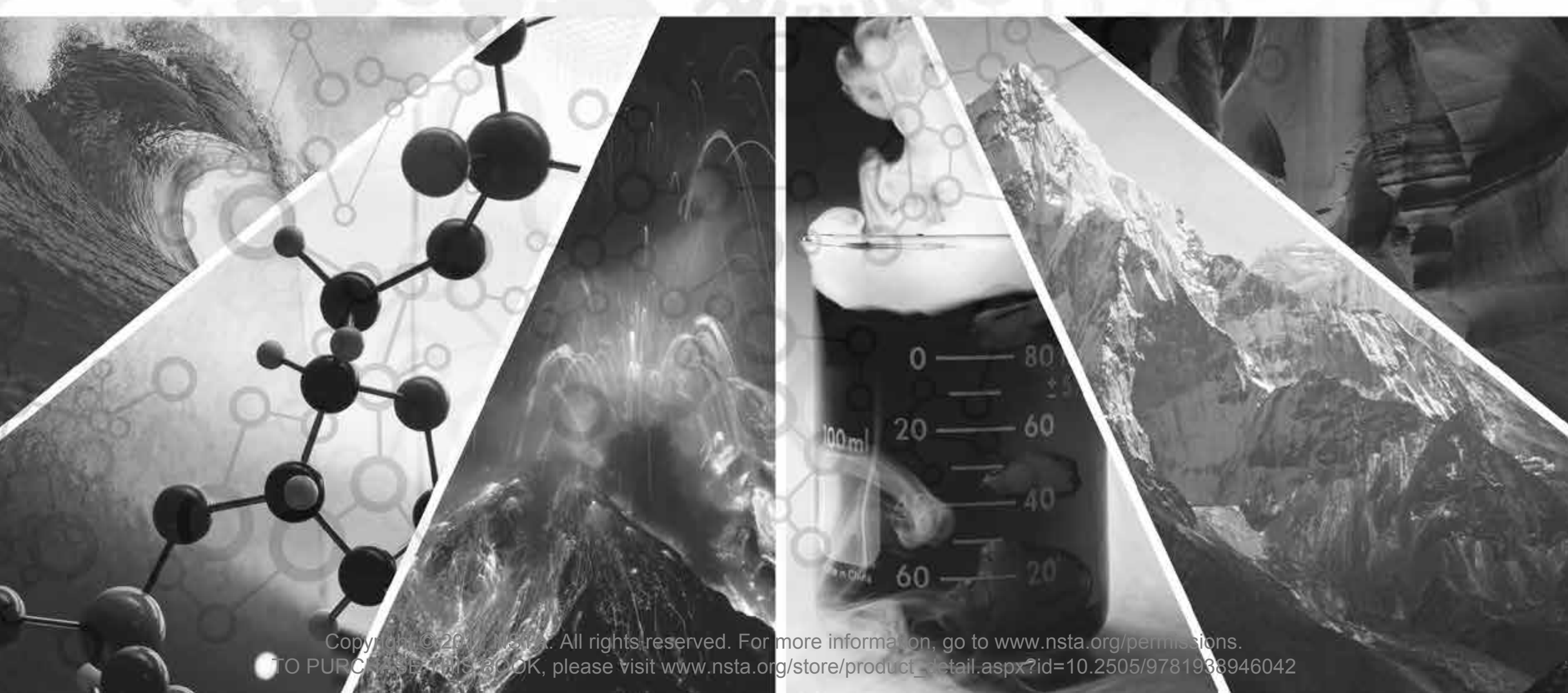

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National Science Teachers Association
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CONTENTS

SECTION 2 (*CONTINUED*)

SECTION 3

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Cynthia Passmore is a professor specializing in science education at the University of California, Davis, School of Education, where she instructs future science educators in the teacher education program. She completed her doctoral work at the University of Wisconsin, Madison. Before that, she was a high school science teacher in southern California and Wisconsin and served as a Peace Corps Volunteer in Malawi. Her research focuses on the role of models and modeling in student learning, curriculum design, and teacher professional development. She investigates model-based reasoning in a range of contexts and is particularly interested in understanding how the design of learning environments interacts with students' reasoning practices. In recent years, she has collaborated with groups of teachers to interpret and implement the vision of science education described in the *NGSS*. She has been the principal investigator of several large grants from the NSF and other agencies and foundations. Currently, she is working with collaborators to develop a year-long high school biology instructional resource package supporting the *NGSS*. She has coauthored papers on modeling in science education that have been published in journals such as the *International Journal of Science Education, Journal of Research in Science Teaching*, *School Science and Mathematics,* and *Science and Education*.

Brian J. Reiser is a professor of learning sciences at Northwestern University. He earned his PhD in cognitive science from Yale University. His current research examines how to make the scientific practices of argumentation, explanation, and modeling meaningful and effective for classroom teachers and students. He co-led the development of IQWST (Investigating and Questioning Our World Through Science and Technology), a three-year middle school curriculum that supports students in science practices to develop disciplinary core ideas. He is a member of the National Research Council's Board on Science Education. He has served on the National Research Council committees that authored *A Framework for K–12 Science Education* (which guided the development of the *NGSS*), *Developing Assessments for the Next Generation Science Standards,* and *Guide to Implementing the Next Generation Science Standards*. He has also worked with Achieve on tools to support implementation of the *NGSS*. He is currently collaborating with several state initiatives to design and provide professional development and create curriculum materials for K–12 teachers to support them in implementing in their classrooms the reforms in the *NGSS*.

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3

TOWARD MORE EQUITABLE LEARNING IN SCIENCE

Expanding Relationships Among Students, Teachers, and Science Practices

MEGAN BANG, BRYAN BROWN, ANGELA CALABRESE BARTON, ANN ROSEBERY, AND BETH WARREN[1]

The emphasis on practices in the *Next Generation Science Standards* (*NGSS*) has the potential to shift science education toward more equitable, active, and engaged learning for all students. Realizing this potential is particularly important in relation to students of color, students who speak first languages other than English, and students from low-income communities who, despite numerous waves of reform, have had limited access to high-quality, meaningful opportunities to learn in science.

What is the potential of the emphasis on science practices? It expands the territory of sense-making in science to include more wide-ranging, intellectually powerful practices than what has conventionally been highlighted in school science (e.g., *the* scientific method). Practices such as argumentation, modeling, interpreting data, and communicating represent fundamental ways in which children and adults, across diverse communities, make sense of the world. In this sense, a focus on science practices invites teachers to attend closely to the varied ways in which students argue from evidence or interpret data as a foundation of learning in science, and to build on students' ideas, experiences, and perspectives as a core part of teaching. By attending closely to what students actually say and do in science, teachers can expand the relationships that are possible among themselves, their students, and science. In this way, they can begin to create more equitable opportunities to learn in science for historically underserved students. This chapter describes and illustrates three principles for teachers to consider as they seek to create such opportunities in their science classrooms.

As a society, we have historically failed to provide meaningful, challenging, and engaging science education for students from historically underserved communities. For the most part, students from these communities experience science instruction as disconnected from their experiences in life, their questions about the world, and the concerns of their communities. Not surprisingly, they disengage from science in large numbers.

1. Authors are listed alphabetically.

As recently as 2008, African American, Latino/Latina, and Native American students earned only 17.5% of bachelor's degrees, 14% of master's degrees, and 7% of doctoral degrees awarded in science fields (NSF 2011). These patterns are troubling because they indicate that STEM (science, technology, engineering, and mathematics) career paths and their associated benefits are not available to these students, their families, or their communities. Of equal importance, these patterns show that neither our schools nor our society is benefiting from the voices and participation of these students in critically shaping classroom learning and responses to our increasingly vulnerable social-ecological world.

Inside the science classroom, teachers can play a uniquely powerful role in addressing issues of equity, in particular, by valuing the insights, perspectives, and experiences of students from historically underserved communities as they make sense of scientific phenomena and making the intellectual value of these contributions visible to the students and the class as a whole. Without question, orienting one's science teaching toward equitable practice is an ongoing project of professional learning that takes time and effort. There are actions that one can take immediately, however, to begin making a difference for students. For example, if a student says something you don't understand, ask her to elaborate, to tell you more. Stick with her and her thinking rather than moving quickly on to another student. Moves of this kind are illustrated in action in this chapter. The bottom line is, the more you show genuine intellectual and scientific interest in your students' sense-making, the more you expand the space of possible relations among you, your students, and science. You may be surprised to find that the principles described in this chapter not only deepen your understanding of your students' sense-making and your relationship with your students but also heighten your students' interest in one another's ideas and their engagement with science.

Science Instruction in Historically Underserved Communities

Before moving to the principles and illustrations, we take a step back to explore briefly how it is that students in historically underserved communities have had limited access to high-quality science instruction. The story behind this problem is multifaceted. One contributing factor is that schools in underserved communities do not benefit from the same resources as schools in middle-income, affluent, and often European American communities. Resource inequalities range from differences in the number of well-prepared science teachers to the number of rigorous, exciting science courses offered to the state of facilities and quality of computers, laboratories, and textbooks.

Another, less obvious factor has to do with the rather narrow range (or repertoire) of ways of speaking, knowing, acting, and valuing that are privileged in our public schools.

These include, for example, known-answer questions, taxonomic thinking, and strict turn-taking. Often identified with aspects of European American, middle-class cultural practice, the more these ways of thinking, talking, and acting are privileged in the classroom, the more they limit the participation and sense of belonging of students from underserved communities, all of whom command ways of talking and thinking that are more wide-ranging and equally intellectually powerful as those privileged in school. The lack of connection between students' diverse repertoires and what teachers expect often becomes a ground of misunderstanding and misinterpretation.

For example, students from European American middle-class families learn at an early age to name and organize objects according to observable characteristics (e.g., color, shape). This way of thinking prepares students for the kinds of classification systems prevalent in school science, such as hierarchical taxonomies that define groups of biological organisms based on shared characteristics. Such systems are both useful and powerful but, like any system, are also limited. Biological knowledge may also be organized in other powerful ways. One is according to the relative roles and relationships of organisms to each other and within larger systems of life and living. Research in some Indigenous communities has demonstrated that, in fact, children and adults organize their knowledge of organisms relationally, developing focus on ecological systems instead of taxonomical categories and focusing on properties of kinds, and they apprentice their children into these systems at an early age (e.g., Medin and Bang 2014). Therefore, if a child is asked a question that requires classifying something as one thing or another, she may answer with a more nuanced, relational response. But because relational knowledge systems are not privileged in school science, she may be heard by her teacher as confused, off topic, or even wrong. Importantly, this perspective increasingly stands in tension with ecologically oriented scientific disciplines concerned with urgent issues of climate change and its intersection with social and economic justice.

The privileging in school of European American middle-class culture and ways of knowing extends to students' sense-making practices as well. For example, schools tend to accord higher status to explanations that are expository or definitional in nature. These modes of explaining are common in European American middle-class communities. Explanatory modes commonly used in other communities, such as forms of storytelling and uses of metaphor, are not accorded the same intellectual status in the classroom, despite the deep connections between these modes and scientific theorizing, explanation, and modeling (Warren et al. 2001).

Human beings, no matter who we are, where we live, or what language we speak at home, develop our ways of knowing, talking, valuing, and acting as we live our day-to-day lives inside family and community. These ways of living are what is now understood as *culture.* Indeed, across communities, human beings make sense of the world in ways that are both similar and different. In other words, the cultural practices of communities are both overlapping and varied. One implication of this is that in school, as in all other spheres of life, learning and teaching are cultural processes in which the diverse experiences, ideas, perspectives, histories, and values of teachers, students, and disciplines (e.g., science) interact with one another in complex ways (Gutiérrez, Baquedano-López, and Tejeda 1999; Nasir et al. 2014). Understanding that learning and teaching are cultural processes, wherein certain ways of thinking, talking, acting, and valuing may be privileged over others, is powerful for teachers in creating more equitable opportunities for science learning.

We are suggesting that the diversity of ways that all students make sense of the world—that is, their sense-making repertoires—affords teachers powerful opportunities to create expansive science instruction (Tan and Calabrese Barton 2012). By *expansive,* we mean, first, that teachers and students together approach scientific phenomena from varied perspectives, expanding the conventional school repertoire. Second, we mean that teachers and students together narrate deep connections between phenomena and their experience, raise and explore unexpected questions, and engage routinely with unspoken aspects of phenomena (e.g., Is water alive?). Creating equitable learning opportunities depends critically on teachers' skill in seeing and hearing students' ideas and reasoning as *connected* to science (as opposed to being off topic or, worse, disruptive). When teachers see these connections, they can then expand the range of scientific practices and ideas traditionally valued in school (Calabrese Barton and Tan 2010).

Making the Shift in Practice

What does shifting toward equitable, culturally expansive sense-making mean for teacher practice? To illustrate the kinds of opportunities and challenges that arise in routine classroom interactions, we present an actual classroom event (Warren and Rosebery 2011). The event occurred in a combined first- and second-grade classroom of students from diverse linguistic, socioeconomic, and ethnic communities (African American, European American, and various immigrant communities from Brazil, Cape Verde, Ethiopia, Eritrea, and Haiti). Ms. T is a European American teacher who was a participant in a professional learning community with other teachers. She was investigating her practice, in particular, how she was interpreting and responding to her students' varied ways of talking and participating in science.

The class was investigating plant growth and development. As part of their study, the class visited a pumpkin farm, planted pumpkin seeds, and created a visual representation of the pumpkin plant's life cycle that they revised throughout their study. They also germinated pumpkin seeds in petri dishes using moist paper towels, *without soil.* One morning, Ms. T planned to introduce her students to a root chamber, a glass-sided container that makes root growth visible *in soil.* To set the stage, she reviewed the work they had done to germinate seeds in paper towels. As she talked, she showed the class a petri dish containing a sprouting seed. Simon, an African American student, called out a question: "Did you put magic beans in there or something?"

When another teacher asked Ms. T about this moment, she said she was initially "irritated" by Simon's question. Her reaction was shaped in part by the way Simon spoke—without raising his hand and with an affect that sounded "provocative" to her. She heard his question as a challenge, at the very least as taking her plan off course. In short, when Simon *first* spoke, Ms. T interpreted his participation from what might be called a social-behavioral rather than a sense-making frame; she did not initially recognize the scientific and intellectual substance of his question.

However, to someone familiar with patterns of African American language use, Simon's ways with words were neither random nor mysterious. He spoke from a powerful intellectual and expressive tradition of African American discourse practices, making use of incisive argumentation, keen wit, and language play (Lee 2007; Mitchell-Kernan 1982; Smitherman 1977, 2000). His question, rather than signaling disrespect, showed attentive intellectual engagement. However, because it was different in form, tone, timing, and content from what is conventionally expected and valued in school, Ms. T was initially unsettled and unsure of his meaning and purpose (Heath 1983, 1989; Lee 2001, 2007; Warren, Ogonowski, and Pothier 2005).

This kind of moment is not unique to Ms. T's classroom, to schooling, or to science education more broadly. Teachers make rapid, consequential interpretations of children's meanings and intentions as a routine part of teaching. Their sensibilities and perspectives with respect to students' sense-making repertoires shape how they interpret these meanings and intentions. Because teachers are trained to expect students' language and ways of making sense to map to those of middle-class European American communities, their skill in recognizing and interpreting other ways is limited (Brown 2004, 2006; Warren and Rosebery 2008). A consequence of this is that the sense-making repertoires of students from historically underserved communities can be misread as signs of disrespect, confusion, digression, lack of knowledge, or disengagement (Nasir 2011).

Fortunately, however, Ms. T had been learning to attune herself to her students' diverse sense-making repertoires and how these related to science. If this had not been the case, let's imagine how Simon might have experienced this interaction. Given her initial feeling of irritation, Ms. T could have easily ignored, deflected, or dismissed his question, or reprimanded him for calling it out. Now, imagine such responses as typical, daily experiences in science. How would Simon, or any student, develop as a scientific thinker or learn a sense of belonging in science? In asking this question, we do not mean to minimize Simon's or other students' resiliency or agency in adverse circumstances (Nasir et al. 2014; Nasir and Saxe 2003; Spencer 2008). However, we also do not want to minimize the cumulative effects involved in these struggles, which is why recognizing and altering their course is, from our perspective, at the heart of creating equitable opportunities to learn in science. The more students are misinterpreted as to their meaning and intention, the more likely they are to be viewed as "disruptive," "inattentive," "unskilled," or "underachieving," reflecting well-worn stereotypes of students from underserved communities. These labels can dramatically shape their experience in schools, relationship with science, and sense of belonging and identity in both (Lee, Spencer, and Harpalani 2003; Martin 2009; Nasir 2011; Sue et al. 2007).

However, because of Ms. T's ongoing examination of her own teaching, her interaction with Simon took a different path. Her immediate reaction of irritation served as a signal to her that *she* was misinterpreting him. She realized that she was not hearing him from a sense-making perspective and did not fully understand him or his concern. What did she do? Rather than dismissing him, *she asked him to say more*—a remarkably simple move with large effects. Her move invited Simon to explain that he was wondering how seeds could germinate *without* soil. This elaboration helped Ms. T see his question in the light of the class's work up to that point, which had foregrounded the importance of soil in plant growth, as had her introduction of the root chamber. As Simon elaborated, she understood that his question was marking a *contradiction* between the class's experience germinating seeds in petri dishes *without* soil and the work they had done to establish soil as a condition *necessary* for plant growth. This allowed Ms. T to recognize and comment on Simon's detailed insight, connect it more fully to the class's past work and her plan for the day, and return later to the contradiction he had raised.

By inviting Simon to elaborate his thinking, she gave him the opportunity to identify an important asymmetry in representations of plant growth used in the classroom. Ms. T's response opened a space of new possible relationships to science and science practices, a space in which Simon was positioned as a powerful, engaged, and critical scientific thinker. In this way, Ms. T, by constructing meaning *with* Simon, transformed a potential site of struggle—in this case, located inside a core practice of question asking about scientific representations—into an expansive learning opportunity in science for Simon and the class as a whole.

Our goal in this chapter is to share three principles that teachers can experiment with as they work to create more equitable learning opportunities in science. These principles can help position teachers and students to engage in expansive science learning. In the next section, we present the principles and illustrate the ways that students' everyday sense-making practices resonate and connect with the broad outline of science practices highlighted in *A Framework for K–12 Science Education* (*Framework;* NRC 2012) and the *NGSS* (NGSS Lead States 2013). The vignettes show how science practices and students' sense-making repertoires can be brought together to create scientifically meaningful learning. Each illustrates students engaging in science practices in ways that broaden valued relationships among teachers, students, and scientific phenomena.

Expanding Meaningful Opportunities to Learn in Science: Three Principles

- **Principle 1: Notice sense-making repertoires.** Attend to, listen to, and think about students' diverse sense-making as connecting to science practices.
- **Principle 2: Support sense-making.** Actively support students in using their sense-making repertoires and experiences as critical tools in engaging with science practices.
- **Principle 3: Engage diverse sense-making.** Engage students in understanding how scientific practices and knowledge are always developing and how their own community histories, values, and practices have contributed to scientific understanding and problem solving and will continue to do so.

In our partnerships with teachers, we have found that through attention to these principles, teachers learn to see and hear the deep connections between their students' sense-making and scientific practices and ideas. Seeing these connections allows teachers to recognize and create rich opportunities to engage with science practices and students' sense-making as a core part of science learning and teaching.

Science Practices in Culturally Expansive Learning

In this section, we share three vignettes focused on science practices identified in the *Framework* and the *NGSS.* The vignettes vary in type of learning environment, student community and age, conceptual domain, and science practice focus. Each illustrates one or more of the principles in action, highlighting ways in which they can be used to foster expansive learning in science.

The first vignette, "There Was a Bullfrog!" focuses on a group of Native American middle school–aged students and their teachers as they transformed a conventional macro-invertebrate indicator task (water sampling to determine water health) to reflect Indigenous community histories, values, and systems of knowing. The second vignette, "But What Would Granny Say?" tells the story of how a group of lower-income and African American youth participating in an after-school program for middle school students used their community-based sense-making repertoires to develop and present an evidence-based solution to a real-life engineering design problem: recommending the placements of three skylights in the roof of their community center. The third vignette, "Pause: Without Me Nothing Matters …," describes how a group of African American high school students integrated scientific explanation with formal aspects of lyricism—a sense-making repertoire integral to language use in hip-hop—to produce videos of the human urinary and digestive systems for a fifth-grade audience.

Introduction to Vignette 1: "There Was a Bullfrog! Investigating the Oxbow"

In this vignette, a group of Native American middle school–aged students and their teachers investigated biodiversity and ecological health at a local forest preserve in a large city in the Midwest (aligned with LS2.A: Interdependent Relationships in Ecosystems, LS2.C: Ecosystems Dynamics, Functioning, and Resilience, and LS4.D: Biodiversity and Humans). This narrative explores how the teachers' ongoing close attention to their students' thinking (principle 1) created learning opportunities that actively supported the students in using their own experiences to engage in scientific practice (principle 2) and at the same time connected meaningfully to the students' community histories, values, and practices (principle 3).

The episode is part of a larger designed unit in which the students were investigating the biodiversity and health of an oxbow. An oxbow is a place where a river used to flow but, over geologic time, the course of the river changed, sometimes forming lakes and other times creating unique ecological niches in the former river beds. This vignette is in a place where an ecological niche has formed, and the still-flowing river is nearby. The river sometimes floods and makes its old course visible. During the investigation, the teachers and students engaged with several science practices from the *NGSS*, including Asking Questions and Defining Problems (practice 1), Planning and Carrying Out Investigations (practice 3), Constructing Explanations and Designing Solutions (practice 6), and, to an extent, Engaging in Argument From Evidence (practice 7). The oxbow was also a place where the students, their families, and other community members harvested culturally salient plants for medicinal and culinary purposes. This explicit connection to students' lives was designed into instruction intentionally to engage principle 3, which is often not part of science learning environments. Importantly, the teachers recognized that students are often given messages that science originated with Western Europe, reinforcing the stereotyped perception that science is something only white males do. Similarly to the case with Ms. T and Simon, the teachers worked to uncover how this positioning occurs in moment-to-moment interactions in science teaching and learning. This vignette illustrates how close attention to and support of students' sense-making can at times be planned and straightforward but at other times must be emergent and nuanced in the way it lives in the stances, language uses, and classroom practices in which teachers and students engage.

The teachers, in partnership with parents and other community members, created lessons that built on family-based and community-based practices (e.g., harvesting plants for a variety of purposes) and on science practices and core ideas within life sciences and Earth and space sciences (reflective of principle 3). A key aspect of this work developed around the kinds of values and relationships that are constructed during science teaching and learning and, more specifically, around the place of human beings and their relations with the rest of the natural world (LS4.D: Biodiversity and Humans). The teachers came to see how science classrooms implicitly and explicitly define relationships among entities (e.g., animals, plants, and natural elements such as water) and position human relations with the natural world in ways that are often culturally and historically inflected by European American norms and values, and that in some cases may not reflect contemporary scientific understanding. They referred to this positioning of human beings in relation to the natural world as "part of," which reflects Indigenous perspectives, or "apart from," which reflects European American perspectives. (To learn more about what the teachers did that led them to this realization, see Medin and Bang 2014. To learn more about the positioning of human beings as part of or apart from the natural world, see Kawagley and Barnhardt 1999.)

Not unlike the future we imagined for Simon if his experiences in science were consistently misunderstood, what would a history of experience being apart from versus a part of nature mean for these students? A singular example of this relational dynamic may seem unremarkable, but the teachers recognized that the cumulative effect of this positioning would narrow the possible space for Native students' learning in science. In particular, doing so made Native students feel and think that doing science reflected European American values and perspectives, not those of their communities. In this vignette, we explore a specific event to exemplify these dynamics and how these relations shaped engagement with science practices.

Vignette 1: "There Was a Bullfrog! Investigating the Oxbow"

As part of their field investigation of biodiversity and ecological health at the forest preserve, the students and teachers wanted to assess the health of the river at the oxbow. In particular, they wanted to know what about the oxbow made it possible for both wetland plants and prairie plants, whose needs for water and soil are quite different, to grow in relative proximity to one another. In earlier lessons at the site, the students and teachers had learned about indicator species and indicators of ecosystem health primarily focused on wetland and prairie plants. They wanted to use this knowledge as part of their assessment of the health of the oxbow and to help them answer their question about wetland and prairie plants. To do this, they planned an on-site investigation that included collecting and analyzing water samples for the presence or absence of indicator macro-invertebrates to construct an explanation about water quality.

As part of their instructional design work, the teachers adapted a relatively canonical macro-invertebrate indicator task and transformed it in two important ways. The first reflected their attention to relationships and human positioning. The teachers felt that the standard protocol typically used in this activity (standing at the edge of a river and collecting samples using a dipping method) implicitly reflected an "apart from" stance because it separated the students from the river. They decided that their students needed to feel the river and develop a sense of being a part of the river. Thus, the plan was to have the students put on waist-high waders and immerse themselves in the river to collect their data.

During their walk to the river's edge, the teachers and students broke into small groups and made informal observations of health indicators. They talked about and looked for frogs because frogs are especially sensitive to water quality. At the river's edge, the teachers incorporated a community-based story that reinforced the students' community values and positioned the activity and the students as a part of a longer history of Indigenous peoples, thereby creating an expansive space for student learning (principle 3).

Importantly, this move also increased the teachers' attunement to their students' sense-making repertoires (principle 1). We now take a close look at how the teachers and students co-constructed the beginning of this adapted macro-invertebrate activity. This event involved three teachers, Allan, Ashley, and Rick, and five students, Eric, Sarah, Ellen, Greg, and Rachel. Allan started to explain the activity and its learning objectives by highlighting the data collection protocol they would use and the relationship between pollution and the presence or absence of organisms. Without realizing it, his explanation left unspoken and invisible the relationships among humans, pollution, and the organisms that students would be looking for, implicitly supporting a view of humans as apart from nature.

Ashley, a second teacher, recognized this and elaborated on Allan's explanation, connecting the students' cultural practices to the river and its health. She offered a view of humans as a part of the ecosystem they were investigating and connected to plants and other animals, thus motivating the activity as directly meaningful to students' lives: "One of the reasons that this is important is that we've harvested medicine from this place, right? And this river feeds the plants and animal life that's here. We want to make sure that we're harvesting medicine when it's ready to be harvested. In addition to finding out just basic health indicators, we also want to know the health of the system here."

Ashley's expanded framing gave explicit voice to an "a part of" stance and repositioned students' community-based practices as connected to their learning objectives. Further, she expanded the intellectual space of the conversation by articulating how the plants and animals are affected by the health of the river, thus reinforcing an "a part of" view of possible relations. Finally, she reconnected the relationship between macro-invertebrates and water quality introduced by Allan but in a broader space of relations.

As he listened to Ashley, Allan recognized the reframing she was doing and extended it to make visible to the students the plants' active relationships with the local habitat: "All right, so Ashley is right on. The plants that we use to heal ourselves are going to heal the Earth before they're ready for us. So if we find out that this place is unhealthy, we're not going to want to use the plants here because they're not ready to be used for us; they still have to work on the Earth first."

Allan has implied that the data they are collecting are going to help them assess whether the ecosystem is healthy. Significantly, he positioned humans in direct and deferential relationships to both plants and habitat, reflecting the values of students' communities. In this way, Allan expanded views of human–nature relations often defined hierarchically by European American cultural values to reflect students' community-based sense-making repertoires and connect with the purpose of the scientific investigation.

A student, Eric, then asked, "If it's nasty, why are we going in?"

Not unlike Ms. T's initial reaction to Simon's question, Allan was caught off guard and interpreted Eric's question as a challenge to him and the activity. However, unlike Ms. T, he didn't pause to reflect on whether he might be misinterpreting Eric. He responded, "The water isn't *that* unhealthy so there isn't anything to worry about."

In the moment, he was more concerned with moving the activity forward than with connecting Eric's thinking with the learning goals at hand. As a result, he positioned Eric as disruptive rather than as deeply engaged with the science, in effect, narrowing the opportunity to learn for Eric and the other students.

Another student, Sarah, dissatisfied with Allan's response to Eric, commented sarcastically, "Well, I guess we'll gain special powers [if we fall in]."

Sarah seems to have understood Eric's question as relevant to their activity and recognized Allan's response as a dismissal of its importance. Crosstalk among the students erupted, reflecting both concern and laughter about the exchange and Allan's response to Eric's question. Again, Ashley stepped in to reframe the interaction, propelling the students and teachers into a conversation that connected Eric's question to the intellectual agenda of the class. She prompted them to reflect on the relevance of their observations of indicator species during their walk to the river as a way to reconsider Eric's question. In this seemingly simple reframing, Ashley opened the space for students to connect their observations and construct evidence-based claims to a question driven by a student. The students' engagement transformed instantly:

Ashley: "But we did see some health indicators. When my group was walking along the river—"

Sarah: "There was a bullfrog, no?"

Ashley: "There was a—"

Greg: "There was a bullfrog!"

Allan: "Did our group find—"

Ellen: "Tadpoles!"

Sarah: "Tadpoles! We seen them."

Allan: "They were actually little frogs."

Rick: "And somebody found a big clamshell? So that big clamshell that you guys found …"

In this Aha moment, bullfrogs and clamshells came alive as "a part of" the oxbow ecosystem rather than as individual species the students had observed. This reflects the disciplinary core idea in the *NGSS* of understanding interdependent relationships in ecosystems. Based on this, the students also immediately realized that the water quality was probably not "nasty," addressing Eric's and Sarah's expressed concerns.

We want to pause to step through some of the implications in this interaction as the students' excitement and insights erupted. First, notice the immediate shift in Sarah's participation. Her first comment expressed sarcasm toward Allan's response. Her second comment, however, took up Ashley's redirection; she was so excited she even interrupted Ashley to connect to it. Sarah's excitement reflected her emerging understanding of interdependent relationships in ecosystems as well as her ability to connect their frog observation data to the kind of explanation about the water's health that Ashley was prompting them to explore.

Greg, another student, also interrupted Ashley to confirm Sarah's observation. Then Allan, who recognized the power of Ashley's reframing, invited other students to make similar connections from their observations. Ellen and Sarah excitedly shared their observations: "Tadpoles!" Rick, another teacher, then connected the students' observations to another indicator species, freshwater clams. At this point there was an explosion of talk as the students shared their observations of health indicators during their walk to the river.

Excited by this brief interaction, a group of girls then led the way *into* the river to begin data collection. The students spent an hour sampling the water, matching their samples to a macro-invertebrate identification sheet, and recording their data. Then they got together in their small groups and developed a claim about the health of the river based on their evidence. Eventually they reconvened as a large group to share claims and explore their evidence.

In this episode, we see the teachers grappling with and continually working with the three principles identified above, from noticing students' sense-making (principle 1), to designing activities that support students' sense-making and engagement with science practices (principle 2), to engaging students in understanding how their own community histories, values, and practices are deeply relevant to scientific understanding and problem solving (principle 3). By engaging in creative and principled instructional work, they created new relations among themselves, their students, and scientific phenomena. They wove into the students' learning experience serious attention to different ways of understanding the place of human beings and their relations with the rest of the natural world reflective of different values and knowledge systems. Finally, the in-the-moment exchange between teachers and students highlights both the complexities and opportunities possible in learning environments where intersections among science practices and students' ideas and sense-making repertoires are nurtured.

We do not underestimate the challenges faced by teachers in creating more equitable, culturally expansive learning in science, especially in light of the many pressures they face, including those associated with high-stakes achievement tests and the need to move activities and curricula forward. However, this vignette demonstrates that it is both possible and effective to strategically adapt conventional curricular materials guided by the three principles and to create meaningful learning experiences in science for students from historically underserved communities. The design work described here moves beyond static views of culture that, when applied to curriculum and instruction, often result in simplified and stereotyped cultural connections that are typically added on to preexisting curricula, without thoughtful reflection and analysis informed by the teaching principles offered in this chapter. Indeed, while a "culture-added" approach has been widely advocated and used, it has not achieved the desired results (Hermes 2000; Yazzie-Mintz 2007). In this example, had the adaptation stopped with the addition of the opening story, it seems unlikely that expansive learning would have occurred. The teachers in the river study worked actively to see how students' community-based sense-making repertoires could be built on to create a culturally expansive space of science learning at various levels of practice. Importantly, this occurred in the small and regular interactions in classrooms (e.g., introducing lessons and responding to questions) and in the field. Working to hear students in different ways in routine classroom interactions does not require significant additional time; rather, it requires a shift in the stances and ways of noticing and interpreting students' talk and activity—especially those of students from historically underserved communities.

Introduction to Vignette 2: "But What Would Granny Say? The Skylight Investigation"

In the summer of 2009, the Great Lakes City Youth Club, a neighborhood youth organization serving a predominantly lower-income and African American population, had a new energy-efficient roof installed that included skylights. The club leaders requested that the youths involved in GET City, a year-round green energy science and engineering program, determine the locations for the skylights based on their knowledge of energy-efficient building design (e.g., LEED certification).

We felt this was an excellent opportunity to engage youths in at least two core engineering practices: (1) defining problems and (2) designing solutions. In particular, we felt this would be a good opportunity to help the youths in more precisely understanding a design task's boundaries, including its criteria and constraints from this integrated vantage point. We were concerned with how to support the youths in seeking out, analyzing, and integrating both scientific and community knowledge as they sought to make the problem space clearer and more finely constrained while also taking on layers of complexity. At the same time, we wanted to support the youths in systematically refining design constraints and in evaluating possible solutions toward optimization. This practice includes cycles of prototyping solutions, designing and conducting tests toward optimizing solutions, gathering and analyzing data from multiple perspectives, and engaging in dialogue on complicated conflicts in perspective and design trade-offs. We view ongoing communication among design partners and with stakeholders as elemental to this practice.

Vignette 2: "But What Would Granny Say? The Skylight Investigation"

To develop recommendations for the best placement for the skylights, the teacher began by eliciting students' prior knowledge and understanding about skylights. A student, Tami, drawing from previous learning experiences in GET City around engineering, suggested they conduct a community needs assessment. The group talked briefly about the assessment done previously and then focused on what they needed to learn and what kinds of data would help them to learn it through the community needs assessment. The youths began to define the design problem posed by "Where should the skylights go?" through a set of criteria that mattered to them. Their ideas for the community needs assessment reflected their experiences at the club—playing basketball, finding something to do in stormy weather, socializing, and doing homework, among other things. The youths and teacher collaboratively began to more precisely define the design task's criteria and constraints.

Later, in explaining their findings to the club leaders, Chantelle, one of the students, captured part of the problem's design complexity when she said, "First, we decided on the criteria that we thought would add most in the placement of the skylight. We thought about how the room was used, including the number of hours the room is used, who uses the room, and for what reason. How many people use the room? Then we thought about how a skylight might impact the room, including amount of natural light, light intensity, reliability, safety, and beauty—sweetness—how it might affect work performance in varying conditions."

Here, we see Chantelle summarizing the criteria the youths settled on, including physical conditions (the amount of natural lighting a room receives), environmental issues (saving electricity), social concerns (sweetness), and, as we will see, equal access. That they felt they could include a sweetness factor was particularly salient to them. They initially worried that others might not view sweetness as scientific, despite the fact that this was critically important to them. Figuring out that their experiences mattered in establishing criteria helped the youths develop a sense of belonging in this design problem.

The youths surveyed 12 rooms, and each room was scored on a scale of 1 to 3 for each of their criteria (e.g., the need for natural lighting, light intensity, light reliability, safety, sweetness, and performance) and was assigned a "priority" rating based on a scale of 1 to 10 determined by the youths. The data were compiled into charts, and then they began to analyze it and interpret their findings (Figure 3.1). They noticed some contradictions in the data around needs and priority scores. A conversation ensued about the asymmetries in their scores.

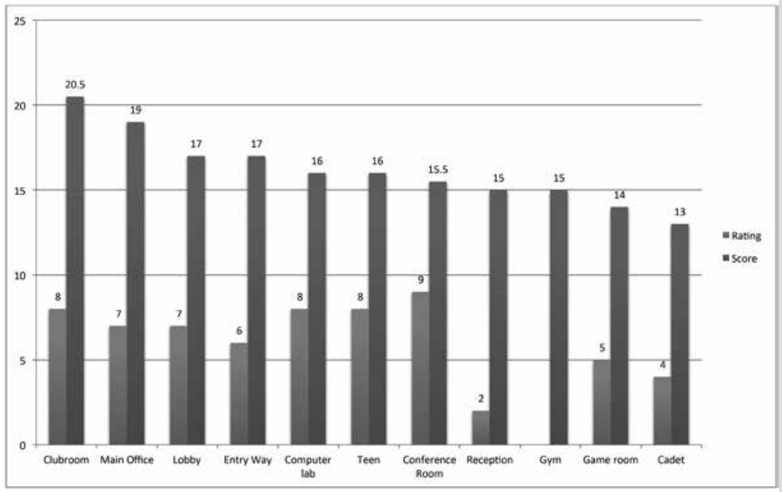
After some deliberation, Patricia offered a solution: "The criteria that rated high in the club room were different from the criteria that rated high in the conference room or the gym. The club room does not have any natural lighting and is used by lots of kids, but the conference room does have some natural lighting, but it is used for a lot more hours. … I think we should talk to Granny."

Granny is a community elder. Everyone, adults included, calls her Granny. She is not in charge at the club, but her opinion matters. As one of the youths explained, "You have to run everything by Granny or it might not work out."

The youths took their questions and data analysis to Granny. They showed her their survey, their charts, and the differences in scores. Granny carefully looked at these documents and offered critical feedback. She suggested that they might want to look at the actual ceilings in the rooms. Did the ceilings look as if they could be modified to fit a skylight? She also suggested that the youths might look more closely at their last stated criterion: What would be fair to the different members of the club? Lastly, she suggested that the youths ask around to see if other people at the club had other ideas about their data.

In this part of the investigation, the youths were engaged in an aspect of practice 6, Constructing Explanations and Designing Solutions, because they were constructing and revising explanations based on evidence obtained from a variety of sources and peer review. They went to Granny with a question of how to deal with the asymmetries as they attempted to resolve a dilemma in the interpretation of their data. They needed to consider how to revise their initial approach and interpretation of data for determining the

Figure 3.1
Data collected about the various rooms at the club



location of the skylights, and they needed to seek out peer review and critique to do so. In other words, the youths began to see that their needs assessment was only one form of data. While important, it was not enough. They decided they needed to show their results to people at the club and get their take on what they thought of the criteria they listed and how they rated the rooms for these criteria.

While critique and iterative refinement are central to engaging deeply in science practices, the youths approached this practice in a socially meaningful way that also reflected a view of science as "a larger ensemble of activities that includes networks of participants and institutions" (NGSS Lead States 2013, p. 43). Granny ultimately took the youths back to the intersection of the design problem and the human, social element involved in their investigation. The youths' design solutions had to take account of the evidence they had collected *and* had to take account of—that is, respect—the forms of life of the people who work and play at the club. This recognition led the youths to revisit each room and engage more community members in the process. Ultimately, Granny's comments caused the youths to embrace the complexity of their data and to situate the data in a broader ecology of concerns that mattered in the lives of people at the club.

In their final report, Tami and Bethany wrote about the placement of one skylight in the club room: "The club room should get one of the skylights because it has no natural light; it got a high rating of 28.5 (the highest rating of all). It also often has kids in it during activities such as healthy habits and gogirlsgo; it also is used for lunch. … The club room should get a skylight because compared to the other candidates, the clubroom has absolutely no natural light and natural light is proven to make people happier, healthier, and save more energy. When you are eating and participating in activities, you need energy. … The cool factor would be that the club room would be much cooler in many ways, such as, we wouldn't have to waste as much electricity and that we could look out of it. lol. And, Granny said that it was a great idea!"

The youths formally presented their recommendations for three skylight locations to club leaders and the roof contractor using data from their needs assessment and follow-up investigation. Their recommendations were accepted, and the skylights were installed in the summer of 2010.

The real-world, real-time design work encouraged by the *Framework* (NRC 2012) and the *NGSS* (NGSS Lead States 2013) emphasizes creating authentic contexts for youths to develop their abilities to design an investigation, analyze and interpret data, and design solutions. The teacher noted that she worried that the eight-week investigation, findings, and design solution would not be accepted by the club leaders or the engineering firm for reasons outside of her control. However, she believed that the youths' careful work in incorporating a range of design concerns and clearly explaining the rationale behind their design solutions made their efforts persuasive and effective. They positioned themselves as experts at the same time that they explicitly broadened the participation of members of their community.

Returning to our three principles for transformative science education, in this vignette example, the attention to student sense-making repertoires (principle 1) meant valuing the intellectual contribution and language of "sweetness" in the investigation. Importantly, while this term may sit outside what is normatively expected as part of scientific language, this example shows how using this term expanded the scope of the investigation and deepened science learning. The investigation also reflected principle 2, incorporating students' *experiences of 21st-century life as critical tools in engaging with* *science practices* by incorporating *why* the youths attended the club and *what* they cared about to shape *how they sought to design solutions.* It mattered to the investigation that the youths wanted the teen and club rooms to be "sweet spaces." It also mattered that these skylights were equitably distributed across the club. These culturally enacted design features did not outweigh—nor were they outweighed by—other criteria, such as the presence of natural lighting or room location. The students' and community's experiences and values infiltrated the way the students framed the questions they asked about skylight placements, the criteria they developed, how they sought and interpreted their data, and how each of these informed their final design solutions. These values opened up powerful spaces to *expand* the scope of the problem and possible solutions beyond prescriptive procedures and answers.

How teachers interpret, assess, and value the meanings and sense-making repertoires of students like Simon, Eric, or Chantelle is connected to how they understand the practices of science and how they imagine children and youths participating in these practices. Constructing explanatory accounts of phenomena is central to the scientific endeavor. Contrary to the ways scientific explanations are presented in the media and schools, scientific explanations are diverse in nature (Gilbert 1984; Latour and Woolgar 1986). In lab settings, scientists engage in discourse practices that vary from the vernacular to the explicitly scientific. Scientific communications are communal in nature and can occur as scientists share data and ideas in research meetings, conferences, and working groups. Although scientists' explanations of phenomena are commonly portrayed as noncreative and monolithic, they are more diverse than most imagine. Ultimately, authentic scientific explanations oscillate between informal and canonical (Gilbert 1984; Latour and Woolgar 1986). In our final vignette, we consider how an orientation toward expert practices can expand learning opportunities in classrooms.

Introduction to Vignette 3: "Pause: Without Me Nothing Matters ... : Lyricism and Science Explanation"

The *Framework* suggests that the goal of science is to explain phenomena. As a practice, students are expected to construct their own explanations as well as apply standard explanations that they learn (NRC 2012). To do this, teachers encourage students to "construct their own explanations" to compare and reconcile with the standard explanations valued in canonical science. Adopting a culturally relevant lens on this explanation process and fostering all students' explanation practices means that teachers need to intentionally integrate students' sense-making repertoires with scientific ways of explaining. This vignette explores one way of expanding students' repertoires of scientific explanation by integrating aspects of the explanation practice and scientific ideas with the culturally rich language of lyricism. This approach is another example of rejecting deficit perspectives of students' sense-making repertoires; it works to integrate multiple discourses into classroom learning in ways that help students understand the value of their own discourse and scaffolds them into using scientific explanations.

Vignette 3: "Pause: Without Me Nothing Matters ... : Lyricism and Science Explanation"

The Mural and Music Arts Project (MMAP) is a nonprofit group that seeks to help impoverished youths learn to value art and its impact on the world. MMAP provides children with free courses in graphic arts, painting, music, dance, and poetry, and then engages them to use their art to empower the larger community. Recently, MMAP commissioned the production of hip-hop music videos as a way to assist with community education. Youths produced science videos for fifth graders that explored standards-based lessons on the urinary system and the digestive system and were communicated through lyricism, a component of hip-hop.

Lyricism represents a unique variation of literary text that involves detailed, metered, and clever forms of language. To shape their project, students were taught the basic mechanisms of lyricism, which include analogy, simile, personification, and polysemy. The students produced two songs and two music videos that were about 5 minutes long and released them via YouTube (see *www.youtube.com/watch?v=Fab7JRibvMw and www.youtube.com/watch?v=5jRbKtwNKeQ*). The fundamental principle guiding this work involved an assumed relationship between lyricism and the production of scientific explanations. The assumption was that producing complex, lyrically rich explanations would first require students to generate canonical scientific explanations. For example, one student, Bonde, created lyrics to explain how water travels through and is processed in the body. To do this, he had to learn what the kidneys look like and the function they play in the human body. And because his audience was fifth graders, he had to synthesize this information and transform it into an explanatory form that would resonate with young students. Producing contrastive modes of language, a canonical scientific mode and a lyrical mode, helped him develop skill in and understanding of the value of both modes.

Throughout the project, students used different literary forms to produce lyrics that explored and explained scientific phenomena. In some of the lyrics they generated, students put themselves in the role of the phenomenon—or imagined that they were a part of it—offering examples of the anatomical nature and physiological role of the urinary and digestive systems. For example, using lyrical principles of personification, Akil described himself as the urinary system. "I'm your urinary system, just in case you didn't know. I filter good and bad blood to start your urine flow." In this excerpt, Akil provided a description of the physiological function of the urinary system. His explanation of how the system filters the blood and "starts the urine flow" is one that he did not come to by chance. Akil continued his explanatory narrative, here using polysemy: "But instead of the water, this is where the urine falls. Pause: Without me nothing matters, 'cause I'm the middle man to the kidney and the bladder."

In this line, he used the pause sign to mark a common cultural practice in which speakers say, "Pause," to make sure the listener does not misinterpret their statement. He was also suggesting that the physiological structure of the ureters looks like the symbol for pausing: two vertical lines (see Figure 3.2, p. 54). This is scientifically significant because Akil is not only describing what the organs are and the sequence of the filtering process, but how the organs are positioned in the body as they do their filtering work. This incisive double meaning is a striking example of the students' use of polysemy for explanatory purposes.

During their study, students generated short scientific explanations of phenomena as a precursor to their lyric writing. This process was fruitful for Akil because it allowed him to assess his science knowledge at various points as he created his explanatory account and still retain some of the essential elements of his description of the function of the kidneys in the urinary system.

These examples highlight the potential of creating expansive learning spaces in which students can use their sense-making repertoires to develop, refine, and effectively communicate explanations of human biological systems. Pairing the use of lyrical and canonical scientific modes of expression provided students with a rich understanding of the value of multiple forms of language and thus with access to powerful scientific literacies.

Figure 3.2
A screenshot from Akil's music video

What did the students think about their learning process? In interviews, they shared their perceptions of their learning and experiences constructing explanations of scientific phenomena.

One student, Imani, explained, "Obviously, me transferring that information into a more interactive and a more engaging way to where it was like, 'Okay, yeah, I know I'm just basically regurgitating this information, but I'm [making it interesting] so that they can learn better.'"

The program's goals for students' learning clearly went beyond "regurgitating information" and extended to making sense of scientific processes and mechanisms. Imani recognized that the writing process in which he engaged, in which he transformed information from canonical science language into a lyrical version, helped him learn about the biological systems in ways he may not have otherwise: "So yeah, I think that's what drove me to [learning science]. And I don't think I really really retained the information until after I finished the song, which was the most interactive part of the learning."

His reflections suggest that his understanding deepened as he worked on developing his song, and that it wasn't until the song was completed that he felt he'd really learned the science.

Writing lyrics may seem far from generating scientific explanations. However, as the work and words of Akil and Imani demonstrate, inviting students to use their sense-making repertoires to support engagement in scientific practices can be powerful (principle 2). These students engaged in serious intellectual work as they translated canonical scientific explanations into their own voices to create meaningful artifacts for their peers and communities. In this way, they created an alternative, expansive space for learning science.

Concluding Thoughts

As we hope we have shown, in the hands of determined teachers, the practices focus of the *NGSS* and the *Framework* offers the potential to push against prescriptive views of knowing and doing science. In this chapter, we have framed the eight science practices as a wide-ranging repertoire with potential to create more equitable, active, and engaged learning in science for all students. Science practices, taken up in expansive contexts of meaningful engagement with scientific phenomena and with attention to students' diverse sense-making repertoires, concerns, and passions, encompass a rich variety of forms and purposes.

The investigations in the vignettes shared certain design features reflecting the three principles outlined in this chapter. They were extended, rooted in students' and communities' local interests and needs, and developed in response to students' unfolding ideas and work, and they afforded students considerable authority for their learning and aimed at co-constructing understanding. These features were in evidence in students' efforts to explore the biodiversity and health of a local river through an ecological lens integrating Western and Indigenous scientific knowledge systems, solve a green design problem in a local community center, and explain human body systems to elementary students.

The vignettes also illustrated how a culturally expansive perspective on science practices in action can create new opportunities for students from diverse communities to engage meaningfully with science. This perspective allows for more fluid relations between science practices and the sense-making practices in which students engage in their everyday lives. It allows for broader recognition and understanding of students' language use and thinking practices than are typically valued in school. It encourages connections that cut across ideas, phenomena, perspectives, and disciplines in ways that reflect emerging shifts in 21st-century science. In short, it allows for expanded relationships to develop among teachers, their students, and science.

The work that scientists do reflects who they are, what they care about, and how they experience the world. It should be no different for students. It is in recognizing who our students are as cultural beings—the ideas, perspectives, and sense-making resources they bring, the issues they care about, the reasons they have for wanting to do science—that we can expand our efforts to engage them deeply. As students develop their sense-making repertoires within and across multiple domains of cultural activity (including those of science), they also develop critical insight into the relationships among them. For students from historically underserved communities, meaningful participation in science *depends on* engagement with the intersections and tensions in ways of making sense of the world.

Without question, teachers hold considerable power to legitimize students' ideas and sense-making in ways that give meaning to science practices and scientific ideas. We wrote this chapter in the hopes that teachers will feel encouraged to experiment with the principles described as they respond to challenges in taking up a practices focus in their science teaching. The principles are intended as reminders of the importance of recognizing and incorporating students' ideas, sense-making repertoires, and experiences as integral to intellectually powerful meaning-making in science. Working from them, teachers will be in a strong position to create equitable, culturally expansive learning that can transform conventional relationships among themselves, their students, science, and the world.

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References

Brown, B. 2004. Discursive identity: Assimilation into the culture of science and its implications for minority students. *Journal of Research in Science Teaching* 41 (8): 810–834.

Brown, B. 2006. "It isn't no slang that can be said about this stuff": Language, identity, and appropriating science discourse. *Journal of Research in Science Teaching* 43 (1): 96–126.

Calabrese Barton, A., and E. Tan. 2010. We be burnin'! Agency, identity and learning in a green energy program. *Journal of the Learning Sciences.* 19 (2): 187–229

Gilbert, G. N. 1984. *Opening Pandora's box: A sociological analysis of scientists' discourse.* Cambridge, UK: Cambridge University Press.

Gutiérrez, K. D., P. Baquedano-López, and C. Tejeda. 1999. Rethinking diversity: Hybridity and hybrid language practices in the third space. *Mind, Culture, and Activity* 6 (4): 286–303.

Heath, S. B. 1983. *Ways with words: Language, life and work in communities and classrooms.* Cambridge, UK: Cambridge University Press.

Heath, S. B. 1989. Oral and literate traditions among Black Americans living in poverty. *American Psychologist* 44 (2): 367–373.

Hermes, M. 2000. The scientific method, Nintendo, and eagle feathers: Rethinking the meaning of "culture-based" curriculum at an Ojibwe tribal school. *International Journal of Qualitative Studies in Education* 13 (4): 387–400.

Kawagley, A. O., and R. Barnhardt. 1999. Education indigenous to place: Western science meets Native reality. In *Ecological education in action: On weaving education, culture, and the environment,* ed. G. A. Smith and D. R. Williams, 117–140. Albany, NY: State University of New York Press.

Latour, B., and S. Woolgar. 1986. *Laboratory life: The construction of scientific facts.* Princeton, NJ: Princeton University Press.

Lee, C. D. 2001. Is October Brown Chinese? A cultural modeling activity system for underachieving students. *American Educational Research Journal* 38 (1): 97–141.

Lee, C. D. 2007. *Culture, literacy, and learning: Taking bloom in the midst of the whirlwind.* New York: Teachers College Press.

Lee, C. D., M. B. Spencer, and V. Harpalani. 2003. "Every shut eye ain't sleep": Studying how people live culturally. *Educational Researcher* 32 (5): 6–13.

Martin, D. B. 2009. Researching race in mathematics education. *Teachers College Record* 111 (2): 295–338.

Medin, D. L., and M. Bang. 2014. *Who's asking? Native science, Western science, and science education.* Cambridge, MA: MIT Press.

Mitchell-Kernan, C. 1982. Linguistic diversity in the service delivery setting: The case of Black English. In *The Afro-American family: Assessment, treatment, and research issues,* ed. B. A. Bass, G. E. Wyatt, and G. J. Powell, 85–98. Philadelphia: Grune & Stratton.

Nasir, N. I. 2011. *Racialized identities: Race and achievement among African American youth.* Palo Alto, CA: Stanford University Press.

Nasir, N. S., A. S. Rosebery, B. Warren, and C. D. Lee. 2014. Learning as a cultural process: Achieving equity through diversity. In *The Cambridge handbook of the learning sciences,* 2nd ed., ed. R. K. Sawyer, 489–504. New York: Cambridge University Press.

Nasir, N., and G. Saxe. 2003. Ethnic and academic identities: A cultural practice perspective on emerging tensions and their management in the lives of minority students. *Educational Researcher* 32 (5): 14–18.

National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.

National Science Foundation (NSF). 2011. *Women, minorities, and persons with disabilities in science and engineering: 2011.* Arlington, VA: NSF.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

Smitherman, G. 1977. *Talkin and testifyin: The language of Black America.* Vol. 51. Detroit, MI: Wayne State University Press.

Smitherman, G. 2000. *Talkin that talk: Language, culture, and education in African America.* New York: Routledge.

Spencer, M. B. 2008. Lessons learned and opportunities ignored since *Brown v. Board of Education*: Youth development and the myth of a color-blind society. *Educational Researcher* 37 (5): 253–266.

Sue, D. W., C. M. Capodilupo, G. C. Torino, J. M. Bucceri, A. Holder, K. L. Nadal, and M. Esquilin. 2007. Racial microaggressions in everyday life: Implications for clinical practice. *American Psychologist* 62 (4): 271–286.

Tan, E., and A. Calabrese Barton. 2012. *Teaching science and mathematics for empowerment in urban settings.* Chicago: University of Chicago Press.

Warren, B., C. Ballenger, M. Ogonowski, A. S. Rosebery, and J. Hudicourt-Barnes. 2001. Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of Research in Science Teaching* 38 (5): 529–552.

Warren, B., M. Ogonowski, and S. Pothier. 2005. "Everyday" and "scientific": Re-thinking dichotomies in modes of thinking in science learning. In *Everyday matters in science and mathematics: Studies of complex classroom events*, ed. R. Nemirovsky, A. Rosebery, J. Solomon, and B. Warren, 119–148. Mahwah, NJ: Erlbaum.

Warren, B., and A. Rosebery. 2008. Using everyday experience to teach science. In *Teaching science to English language learners*, ed. A. Rosebery and B. Warren, 39–50. Arlington, VA: NSTA Press.

Warren, B., and A. Rosebery. 2011. Navigating interculturality: African American male students and the science classroom. *Journal of African American Males in Education* 2 (1): 98–115.

Yazzie-Mintz, T. 2007. From a place deep inside: Culturally appropriate curriculum as the embodiment of Navajo-ness in classroom pedagogy. *Journal of American Indian Education* 46 (3): 72–93.

INDEX

Page numbers in **boldface** type refer to figures or tables.

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HELPING STUDENTS MAKE SENSE OF THE WORLD USING NEXT GENERATION SCIENCE AND ENGINEERING PRACTICES

When it's time for a game change, you need a guide to the new rules. *Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices* provides a play-by-play understanding of the practices strand of *A Framework for K–12 Science Education (Framework)* and the *Next Generation Science Standards (NGSS)*. Written in clear, nontechnical language, this book provides a wealth of real-world examples to show you what's different about practice-centered teaching and learning at all grade levels. The book addresses three important questions:

1. How will engaging students in science and engineering practices help improve science education?
2. What do the eight practices look like in the classroom?
3. How can educators engage students in practices to bring the *NGSS* to life?

Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices was developed for K–12 science teachers, curriculum developers, teacher educators, and administrators. Many of its authors are researchers who contributed to the *Framework's* initial vision and teachers who are leaders in implementing these ideas in their own science classrooms. If you want a fresh game plan to help students work together to generate and revise knowledge—not just receive and repeat information—this book is for you.

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