What Is (or Should Be) Scientific Evidence Use in K-12 Classrooms?

Katherine L. McNeill[1] and Leema Berland[2]

[1]*Lynch School of Education, Boston College, 140 Commonwealth Avenue, Chestnut Hill 02467, Massachusetts*
[2]*University of Wisconsin-Madison, Madison, Wisconsin*

Abstract: Research and reform efforts frequently identify evidence as an essential component of science classroom instruction to actively engage students in science practices. Despite this agreement on the primacy of evidence, there is a lack of consensus around what counts as "evidence" in k-12 classrooms (e.g., ages 5–18): scholarship and standards in science education define evidence in a variety of ways including empirical data, analogy, personal experience, and scientific theories. We argue that this disagreement results in a wide range of classroom activities around evidence, including ones that recapitulate traditional science instruction focused on final form science and teachers as disseminators of information. In this paper, we develop design heuristics to inform the design of classroom learning environments that productively use scientific evidence for student sensemaking about the natural world by (i) selecting from the range of information a subset to use as scientific evidence; and (ii) designing classroom activities that support students collaboratively making sense of the natural world. In particular, we argue for three design heuristics that could potentially shift science classroom activities away from traditional "problems of practice" to align more closely with the vision of science as a set of practices including: phenomena-based, transformable, and used dialogically. © 2016 Wiley Periodicals, Inc. J Res Sci Teach 9999:XX–XX, 2016
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Recent research, reform documents, and standards describe a transformative vision of science education in which students learn through their active participation in science practices. In this vision of science-as-practice, students develop and demonstrate knowledge in use as they build explanations of phenomena and explanatory models (Berland et al., 2016; Krajcik, Codere, Dahsah, Bayer, & Mun, 2014; Lehrer & Schauble, 2006). This is in contrast to how science has historically been taught, which often focuses on teachers presenting discrete science facts with little opportunity for students to construct knowledge through their participation in science practices (Duschl, 1990; Pruitt, 2014; Roth & Garnier, 2006). We argue in this position paper that scientific evidence—a key component of the science practices (National Research Council [NRC] 2012, 2015)—has the potential to address common problems of practice related to transforming classroom interactions away from traditional science instruction. In particular, scientific evidence can be a lever for changing the work of science learners from individually learning final form and isolated facts to actively participating in knowledge construction practices.

Scientific evidence has this potential both because of its role in science practices and because of the emphasis on evidence in existing policy and research. For example, at the elementary school level, students should be publically reasoning as they develop claims from evidence (Zembal-Saul, 2009) and building explanations where they coordinate theory and evidence (Herrenkohl, Palincsar, Dewater, & Kawasaki, 1999). Furthermore, in secondary schools, students should continue to use evidence to support claims (Sampson & Blanchard, 2012) including as they develop complex causal claims about the natural world (Sandoval & Millwood, 2005). In short, science education and policy appear to agree on the primacy of evidence for students in knowledge construction.

Despite the agreement on the importance of evidence, the field does not have a unified understanding of what counts as evidence use in science classrooms. The term evidence is used by the research community in a variety of ways including as empirical data (e.g., Gotwals & Songer, 2013; Jiménez-Aleixandre & Federico-Agraso, 2009; Sampson & Clark, 2011), scientific theories (Choi, Hand, & Greenbowe, 2013; Erduran, Simon, & Osborne, 2004), analogy (e.g., Crippen, 2012), and personal experiences (e.g., McNeill & Pimentel, 2010; Oliveira, Akerson, & Oldfield, 2012). Furthermore, standards documents, like the Next Generation Science Standards (NGSS) performance expectations in the United States, use the term "evidence" frequently but with a variety of meanings (Kastens, 2015). In addition to the variation in what information counts as evidence, there is also variation in the ways that information is used. Current science instruction uses evidence in a variety of activities (e.g., individual writing, concept cartoons, jigsaws, small group discussions, and whole-class debates) as well as for a variety of functions (e.g., explaining phenomena, depicting science misconceptions, making socioscientific decisions) (Cavagnetto, 2010). We argue that using the word evidence for different types of information and a range of activities diminishes the potential for scientific evidence to act as a lever to transform classroom instruction and address common problems of practice that have been a concern for years in science education.

Thus, our goal in this paper is to present a set of design heuristics that may support science classrooms in enabling students to use "scientific evidence" in ways that align with student participation in science practices. Design heuristics are a set of guidelines to inform the development of future instruction, which are grounded in real classroom challenges (Davis & Krajcik, 2005). In order to develop these design heuristics, we first consider common challenges with traditional science instruction or problems of practice that could impede the science-as-practice vision. We focus on refining the definition and use of "scientific evidence" because, as argued above, it is both ubiquitous and refers to a wide range of activities and information types. We acknowledge that different information sources and activities can play an important role in science classrooms; however, our argument is that using one label for all of these types of information can inhibit the discussion and use of each one. Narrowing what counts as the use of scientific evidence in k-12 classrooms may potentially be a more powerful lever for addressing common challenges in science classrooms.

Problems of Practice: Challenges With Traditional Science Instruction

Science education has frequently been critiqued for not providing k-12 students (e.g., students 5–18 years old) with rich and meaningful experiences in science (NRC, 2012). Problems of practices, or reoccurring dilemmas grounded in the challenges of classroom instruction (Horn & Little, 2010), can serve as barriers for the successful enactment of science practices. As research focused on this new vision of science education is conducted, "pitfalls" (NRC, 2015) and challenges are emerging that we need to consider as a field. In this position paper, we identify three problems of practice, knowing that there are many more; however we focus on these because they

Table 1
Problems of practice in traditional science classrooms

Problem of Practice	Description
Science as final form ideas	Science instruction focused on the memorization of discrete concepts, facts, and laws.
Data as the answer	Students see data as factual and self-evident, rather than understanding evidence as constructed and needs to be interpreted.
Isolated individuals and ideas	Science instruction as characterized by students as individual receivers of isolated ideas.

may be particularly challenging for the turn to science practices in recent reform efforts (see Table 1). Note that when describing these problems of practice we explain why they are problems from the perspective of what we know about both supporting student participation in science practices and how knowledge is constructed in science. We address both of these perspectives in order to demonstrate that these are problems regardless of whether our goal is for students to participate in the scientific endeavor (to develop an "epistemology for science") or for students to learn about the scientific endeavor (i.e., to develop what Russ (2014) calls an "epistemology of science"). After describing these problems of practice, we introduce three design heuristics for "scientific evidence use" that have the potential to address these problems of practice by supporting teachers in moving away from traditional science instruction.

Science as Final Form Ideas

Science instruction is often criticized for focusing on the memorization of discrete concepts, facts, and laws. This focus supports students' perception of science as a set of final form ideas that do not change over time (Duschl, 1990). There is often a focus on one "right answer" rather than an exploration of ideas that includes incorrect or partially correct explanations (NRC, 2015). For example, in the United States, teachers often present science as disconnected facts, algorithms, and definitions (Roth & Garnier, 2006). However, individuals learn by interpreting their observations not through reception of authoritative facts (e.g., Edelson, 2001; Kolodner et al., 2003; Scardamalia & Bereiter, 1991). Moreover, recent reform efforts (NRC, 2007, 2012) and standards documents (NGSS Lead States, 2013) advocate for a new model of proficiency in science in which students are able to apply, explore, and learn science concepts as they participate in science practices such as developing models, analyzing data, and constructing explanations. These reform efforts focus on students developing and revising science ideas themselves, rather than memorizing the ideas of others (Sandoval, Sodian, Koerber, and Wong, 2014) —they directly challenge the perception that science is made up of final form ideas.

This image of science as not being made up of final form ideas similarly aligns with the work of scientists who are continuously refining and revising explanations of the natural world (NRC, 2012). There is no one truth about the natural world, rather scientists construct knowledge using an empirical basis (Harré, 1986). Thus, scientists engage in considerable intellectual and collaborative struggles to explain natural phenomena (Ford, 2008). And, while paradigm shifts occur resulting in the creation of new scientific ideas, there is also the rejection of previous theories (Kuhn, 1962). Thus, science is not final form. Students, similar to scientists, should engage in the practices of science as they consider and critique multiple ideas, instead of being presented with a body of final form facts (Osborne, 2010).

Data as the Answer

When science instruction does involve students working with data, students can still hold views of data and evidence, which differ from the views of the scientific community and are antithetical to student participation in science practices. Unfortunately, students are likely to interpret "data as factual rather than [as] constructed and open to interpretation" (Sandoval & Çam, 2011, p. 401). That is, instead of considering data as constructed, students tend to objectify evidence seeing it as self-evident (Manz, 2016), and in this way, they see data as being the goal of any investigation, and the answer to their questions. For example, students often conduct investigations and collect data without connecting to the research question—they are instead simply following classroom instructions. In these situations, their work is done when they have gathered and described the desired data. There is often little need for them to then work to interpret and make sense of that data (Duschl, 2008).

However, the goal of science is not to describe observations, but to make meaning of those observations in ways that are significant. As Rouse argues, "most truths about the world are scientifically irrelevant or uninteresting; recognizing the difference between important and insignificant claims is indispensable for understanding scientific practice" (1996, p. 26). Consequently, science is more than the work of collecting data to describe nature; scientists work to make sense of nature—to develop understandings of how and why nature works in the ways that it does (Russ, Coffey, Hammer, & Hutchison, 2009; Salmon, 1978; Sandoval & Millwood, 2005).

As argued by Duschl (2000), this sensemaking requires three "transformations" of data or the information observed in nature:

> Transformation 1 is evaluating what raw data become the selected data or evidence.
> Transformation 2 is evaluating how the evidence can be manipulated to locate patterns and models in the selected data. Transformation 3 is evaluating how the patterns and models fit, or do not fit, scientific theories and explanations (p. 190).

This is a cyclical process in which interpretations of nature are used to guide the development and revision of questions, methods for observing nature, and theories and explanations (Duschl, 2000; Krajcik, Berger, & Czerniak, 2002; Windschitl, Thompson, & Braaten, 2008). In short, the work of science entails interpreting observations of phenomena in order to make sense of them—to understand how and why nature works in the ways that it does. Similar to scientists, students need to participate in this interpretation process as well, and this will enable them to move beyond seeing data as the answer.

Isolated Individuals and Ideas

Science classrooms are often characterized by teachers presenting discrete ideas and students as individual receivers (Roth & Garnier, 2006). Dialogic interactions between students are not the norm in science classroom (Newton, Driver, & Osborne, 1999). Even when enacting curriculum explicitly designed to support these transformative student interactions, teachers often adapt the lessons in ways that align with their existing teaching (Berland, 2011) and therefore to more traditional teacher led instruction (McNeill, Pimentel, & Strauss, 2013). There is an outdated, but prevalent, image of students sitting in rows of desks passively receiving information from their science teacher. However, classroom instruction needs to change to meet the ambitious learning goals in new reform efforts in which learners actively construct knowledge within the social processes of a dialogic learning community (Quinn & Bell, 2013).

Students engage in sensemaking not by constructing knowledge individually, or by memorizing the ideas of others, but through a process of social knowledge building in which they

argue about and for their ideas (Ford, 2008; Osborne, 2010). That is, we learn through language that enables us to internalize external events (Vygotsky, 1978). Productive classroom discourse supports student talk in which students' thinking becomes visible not only to the teacher and peers, but also for the students themselves (Duschl, 2008). A focus on social sensemaking in which students substantively attend to one another's ideas can discourage singular forms of sensemaking in which students only use new information to confirm their existing ideas (Ford, 2012). As argued by Bakhtin (1982), social knowledge construction (or "internally persuasive discourse") enables us to take up the ideas of others and make them our own such that those ideas do not remain "isolated and static" but are instead integrated into our understandings of the world (p. 345). Beyond the theoretical arguments, empirical studies have demonstrated the efficacy of collaborative knowledge building in supporting student learning in science (e.g., Asterhan & Schwarz, 2009; Scardamalia & Bereiter, 1994; Von Aufschnaiter, Erduran, Osborne, & Simon, 2008).

Similar to this model of student learning, scientists also engage in a social sensemaking process. While there is no one-way to make sense of the natural world (Pera, 1994; Rudolph, 2003), the science education community and science studies literature consistently portrays scientific knowledge as constructed through a social process of argumentation (Longino, 1990; Osborne, 2010; Pera, 1994). That is, scientific ideas are validated when members of the scientific community construct, debate, and revise possible scientific theories and explanations. As synthesized by Ford (2008) "Individuals do not produce scientific knowledge—communities do" (p. 410). This occurs as scientists communally construct and critique possible scientific ideas—finding possible errors in one another's work to collaboratively develop progressively more valid and reliable interpretations. In contrast to traditional science instruction, students also need to participate in this collaborative sensemaking process.

Design Heuristics for Scientific Evidence Use in Science Classrooms

Consistent with the theoretical framework of "framing" (Goffman, 1974) we argue that key, and sometimes subtle, design features—such as scientific evidence use—can significantly influence the ways in which students participate in their class activities (Hutchison & Hammer, 2010; Rosenberg, Hammer, & Phelan, 2006). For example, students framing an activity as an exchange of ideas might work to hear the ideas of their peers and to have their ideas heard. In contrast, if they are framing an activity as a presentation of final form ideas they may only attend to the teacher. Students' framings also influence how they interpret the actions of others; for example, a student framing a discussion in one way could hear a teacher's question as a genuine request for clarification, while a different framing would suggest that the same question was a "test" (Berland & Hammer, 2012).

Thus, in this paper, we present the three design heuristics for using scientific evidence —phenomena-based, transformable and used dialogically (See Table 2)—that have the potential to help educators to consistently create opportunities for students to frame their activities as opportunities for productive sensemaking. As discussed previously, design heuristics are a set of guidelines grounded in classroom challenges that can be used to develop and guide future instruction (Davis & Krajcik, 2005). Instructional designers often use heuristics when engaged in the development process to address complex problems of practice (York & Ertmer, 2011). However, in science education we often do not explicitly discuss or debate design heuristics for instruction and how they align with current challenges. Thus, while the individual heuristics we have identified are not new—they instead draw on decades of research—we offer them as a cohesive set in order to begin

Table 2

Design heuristics for the use of scientific svidence in K-12 classrooms

Design Heuristic	Problem of Practice	Description of Design Heuristic
Phenomena-based	Science as final form ideas	Information is phenomena-based when it consists of empirical data (e.g., observations or measurements) about phenomena in the natural world. The empirical data can either be first hand experiences, such as students collecting data (e.g., conduct an investigation with balls and ramps), second hand experiences, such as a digital repository of data collected by someone else (e.g., data about the solar system), or a simulation that produces data for students (e.g., a simulation where students can change variables such as friction).
Transformable	Data as the answer	Information is transformable by students when they can manipulate it to find patterns, and evaluate the fit between those patterns and competing claims. This could include students testing different variables, such as conducting multiple trials with different variables, or analyzing data, such as creating graphs and tables to look for patterns.
Used dialogically	Isolated individuals and ideas	Information is used dialogically when students work together to make sense of it. In these social interactions, students engage in discourse in which they construct and critique different ideas to collaboratively build knowledge.

having this conversation to address problems of practice and refine a definition of "scientific evidence use." Recent reform efforts and standards offer an opportunity for change and we see the design heuristics as a potential lever to address these longstanding challenges.

In the following sections, we illustrate each design heuristic and discuss how it helps to address a problem of practice. The three design heuristics for evidence use presented here are not exhaustive, but we use them to explore how evidence can be used in science classrooms to productively support student participation in the science practices. Furthermore, as we will discuss in more detail later, we argue that this scientific evidence should be used in tandem with other information in science classrooms (i.e., evidence is not the only type of information that should be used in classrooms). In considering this, we frame our task as identifying design heuristics that will help researchers and educators enable students to make sense of the natural world through (i) selecting from the range of information the subset that should be used as scientific evidence; and (ii) designing classroom activities that support students in making sense of the natural world. To be clear, these heuristics are meant to support educators in designing effective learning opportunities. We do not view distinctions we describe here as productive for teaching students— these are not characteristics of evidence that should be listed in a science lesson for students to memorize. Rather, they are design heuristics to develop activities, curriculum, and other learning environments that support students in making sense of the natural world.

Design Heuristic 1: Phenomena-Based

The first design heuristic targets the problem of practice that science instruction often focuses on science as final form ideas. Instead of only presenting students with abstract final form science concepts, big ideas in science need to be explicitly linked to natural phenomena. Situating science

ideas within real world contexts "plays a powerful role in facilitating student learning through both motivational and cognitive means" (Rivet & Krajcik, 2008, p. 98). Consequently, the first design heuristic suggests that scientific evidence used in k-12 classrooms should focus on information that is phenomena-based, which consists of empirical data about phenomena in the natural world.

This emphasis on connecting science concepts to natural phenomena has been propagated throughout policy documents. For example, NGSS includes a disciplinary core idea about chemical reactions for middle school students (PS1.B)—"Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants." The performance expectations for this idea are not that students can state the concept, but rather that they should be able to "Analyze and interpret data" (MS-PS1-2[1]) and "Develop and use a model" (MS-PS1-5) for specific examples such as "burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with HCl." By attending to specific, concrete, examples, students can experience science learning as sensemaking about the world around them, rather than as memorizing facts. Students still need to use and apply their understanding of science concepts; however, this information should be used in tandem with scientific evidence. Thus, just as experiences that are related to phenomena drive scientists sensemaking, they are a core component of student scientific sensemaking as well.

Information is phenomena-based when it consists of empirical data (e.g., qualitative observations or quantitative measurements) that are explicitly linked to phenomena from the natural world. Empirical data that is linked to phenomena can come from either first-hand or second-hand experiences. First-hand data experiences are those in which students investigate phenomena and collect their own observations or measurements. These types of experiences are automatically connected to phenomena, because students are experiencing the phenomenon directly in front of them. For example, to return to the previous middle school disciplinary core idea about chemical reactions (PS1.B), students can conduct an investigation in class in which they personally experience a phenomenon such as burning sugar or rusting iron. Students observe and collect empirical data for the specific phenomenon under study resulting in an explicit connection to the natural world.

Second-hand experiences are those in which students are either provided with data collected by other individuals (e.g., data table or data set) or use a simulation that allows them to change variables and collect data. Second-hand data experiences can enable students to explore phenomena that they cannot directly experience in k-12 classrooms such as ones that are too dangerous (e.g., explosive chemical reactions), too slow (e.g., natural selection), too small (e.g., particulate nature of matter), too big (e.g., solar system), or too expensive (e.g., DNA sequencing) (Hug & McNeill, 2008). Consequently, even if a phenomenon cannot be directly observed in a science classroom, learning activities can still be designed to provide more direct links to phenomena. For example, one of the 4th grade earth science disciplinary core ideas in NGSS (2012) states: "The locations of mountain ranges, deep ocean trenches, ocean floor structures, earthquakes and volcanoes occur in patterns. Most earthquakes and volcanoes occur in bands that are often along the boundaries between continents and oceans" (4-ESS2-2). Obviously, this is a concept that would be difficult to observe in most classroom settings. A traditional approach to introducing this concept to students would be to have the text or teacher present the idea. Instead, we (and many others) argue that addressing the problem that science is often depicted as being a set of final form ideas means that the big idea should be more connected to the phenomenon. For example, students could use online resources that provide the locations (e.g., longitude and latitude) of earthquakes and volcanoes across the world. Clicking on a specific location would then bring up a photo or video to help students visualize the area. As such, students

would be experiencing these landforms as physical things in the world, rather than as abstract concepts, thereby contextualizing the data and making it more accessible. In addition, when accessing the data, students could analyze it by creating maps and looking for patterns. It is this analysis that would enable students to investigate the target disciplinary core idea (i.e., moving beyond the existence of the landforms to patterns in their location). Moreover, this analysis means that students would be transforming the information that is phenomena-based and hence it aligns with the second design heuristic—transformable (discussed below in the Section Design Heuristic 2: Transformable).

Using empirical data that is phenomena-based helps communicate that the students are working to make sense of the natural world—they are not receiving abstract, disconnected facts about science. Previously, traditional science instruction often positioned students to be consumers of the sensemaking of others—to use final form ideas constructed by scientists. Consequently, the first design heuristic focuses on what types of information should be used as evidence in k-12 classrooms. Students must have opportunities to explore empirical data, which are explicitly linked to the natural phenomenon under study, in order to support them in being constructors, and not just consumers, of the scientific ideas.

Design Heuristic 2: Transformable

Since students may see empirical observations as the goal of their work—as the answer—instead of open to questioning, critique, and interpretation, focusing on information that is phenomena-based alone (i.e., data) will not necessarily transform classroom practices to align with a science-as-practice vision for science education (Lehrer & Schauble, 2006; NRC, 2012). As such, in addition to being related to phenomena, it is important for students to transform and evaluate information. Without these opportunities, students are likely to frame their science activities as an opportunity to memorize final form facts (be they empirical data or statements of scientific principles) rather than as a time for sensemaking about the natural world.

We address the second problem of practice, data as the answer, with the design heuristic of transformable because data that is transformable requires students to critically consider and interpret the observations and measurements, moving away from accepting the data as the answer. The design heuristic of "transformability" means that we must consider the degree to which the data in question requires and enables the sorts of transformations depicted by Duschl (2000). That is, the data must enable student sensemaking by requiring that students select what data to use, manipulate it to find patterns, and evaluate the fit between those patterns and their expected claim. The act of transforming the data often requires students to use other information, like science ideas, to select and evaluate the patterns. However, we argue that in designing learning environments it is important to think about and use these types of information (e.g., data, science ideas, personal experiences) in different ways to best support students in scientific sensemaking.

In the previous 4th grade example about volcanoes and earthquakes, if students analyzed data by creating maps and looking for patterns, they would be transforming that data. The photographs and videos helped link the data to phenomena, but then students would still need to engage in sensemaking around the data to come up with claims about where volcanoes and earthquakes occur. The transformation highlights those sensemaking aspects. This analysis in itself would not result in an in depth understanding of plate tectonics, but it would create a need for further exploration. In contrast, students could be given an online map that only uses a simplified subset of the data explicitly labeled and highlighted as the ring of fire consisting of the pattern of volcanoes and earthquakes around the Pacific Ocean at the plate boundaries. This online map could still

allow students to click on photos or videos of the different earthquakes and volcanoes aligning with the first design heuristic—phenomena-based; however, it would not address the second design heuristic—transformable. We argue that the transformation of the data (i.e., selecting and manipulating to find patterns) is essential for student sensemaking and for students to not see the data as the answer. Consequently, although the first two design heuristics are related, it is possible to meet one without the other.

As a second example consider a high school teacher asking students to construct an argument about the role of humans in climate change, this teacher could give students access to a database with longitudinal data about greenhouse gas emissions from industry, atmospheric temperatures, and carbon dioxide concentrations. Alternatively, the teacher could supply statements of key information such as "human behaviors release carbon dioxide into the atmosphere." Both of these presentations of information can be used to construct a scientific argument relating humans to climate change. In the second case that includes the statements of information, students would do so without transformation—they use the statements as a whole piece of information or not at all. In contrast, the information in the first case must be transformed in order to be included in the argument—individuals must select which data to use, manipulate it to find patterns, and evaluate the fit between those patterns and the claim (Duschl, 2000).

This heuristic of considering the degree to which data are transformable can only be determined in relation to the question being asked. For example, in the case of the climate change example, the teacher could provide students with the relevant databases and ask them to identify the year with the highest atmospheric temperature or to use the databases to explain whether and how human behavior relates to climate change. The first question does not require transformation of the provided data to answer the question—instead students simply identify (or select) the relevant piece of data and report it. In this case, the data is the answer. In contrast, the second question can only be answered by selecting the data that are most relevant, manipulating that data to reveal patterns and relationships, and then evaluating their understandings against the provided data. In this case, the question could only be answered by transforming the provided data and, as such, the design heuristic of "transformable" would be fulfilled.

In short, the potential transformability of information in k-12 classrooms is impacted both by the information used (i.e., Is it possible to transform the information?), and the relationship between that information, the question being asked, and the structure of the activity (i.e., Does it need to be transformed to answer the current question?).

Design Heuristic 3: Used Dialogically

The final heuristic, used dialogically, addresses the problem of practice in which individuals and ideas are isolated. This design heuristic does so by requiring that educators consider whether and how the available information enables students' collaborative sensemaking. By used dialogically, we mean that information is used and critiqued in a social process with other individuals (Jiménez-Aleixandre & Erduran, 2008). That is, the purpose of information in collaborative sensemaking is to provide grounds upon which students can make, justify, and refute claims (van Eemeren, Grootendorst, Johnson, Plantin, & Willard, 1996; Toulmin, 1958). Dialogic interactions demand that other perspectives be attended to and one's own argument be subject to critique (Kuhn, 2015). Actively participating in discourse in which knowledge is co-constructed as a group enables students to develop more in-depth understandings than if they only worked independently (Newton et al., 1999). Thus, this design heuristic focuses on activity structures and classroom norms that support the development of a classroom community in which students substantively interact with each other around information.

The way in which a teacher structures instruction impacts whether information is used dialogically. For example, consider a middle school science lesson in which students address the question "When a person trains to become an athlete, how does the human body change to become better at releasing energy?" (Regents of the University of California, 2013). Students could have access to data from athletes and non-athletes including variables such as amount of exercise, lung size, mitochondrial protein, and heart rate. In order to support students in using this data dialogically, the teacher could explain to the class that they will be participating in a science seminar, in which students run the conversation with the purpose of using everyone's ideas and questions to build a stronger understanding. To prepare for the science seminar, students could first work in small groups to analyze the data to develop their initial claims and questions for the full class discussion. Then students could have a dialogic discussion in which they question and critique each other's ideas about the data, while the teacher remains outside of the discourse circling quietly taking notes about the students' ideas. In contrast, the same question and data could be explored with a different activity structure, such as asking students to each write their own individual argument and support it with evidence. This type of writing task could still be phenomena-based and require students to transform the data, but it would not create opportunities for students to interact as they collaboratively made sense of the information.

Illustrating the Design Heuristics

Designing learning environments in which students use information in ways that are consistent with the science practices depends on the context. As Rouse (1996) argues, a science practice includes not only the action itself, but also the setting in which the action occurs. Thus, when designing for and understanding students making sense of scientific information, we must examine the context to determine when information is being used as scientific evidence.

To illustrate this point, we take an example from Reiser and colleagues' (Reiser et al., 2001; Tabak & Reiser, 2008) research around high school biology. In this case, students investigate a database (beguile.northwestern.edu) of information about the Finches on the Galapagos Islands in the mid-1970s. The students use this database to figure out why the majority of the Finches died in 1976–1977 and why some were able to survive the catastrophe. The database provides students with: detailed fieldnotes about the finches (i.e., "Its eating a little portulaca and mostly cactus seeds. Occasionally it tries to pry open a tribulus seed, but often gives up after a few trials"); numerical measurements about each observed bird including beak size, wing span, height, and weight, for numerous years before and after 1976; and quantitative and qualitative data about the environment, including other species that live there and weather patterns. Before investigating the database, students watch a video showing how the scientists gathered this information.

Using the three design heuristics for scientific evidence use, we argue that the activities in which the information is offered through this learning environment illustrate productive evidence use for k-12 science classrooms (See High column in Table 3) because:

- It is phenomena-based—not only is the database reporting observations of a natural phenomenon, but it is framed as such; the video helps students understand that the data came directly from observations.
- It is transformable—students can construct graphs comparing any of the variables for which there is quantifiable data, students can search through the qualitative data for characteristics about which they are curious. Through these activities, students are selecting data and finding patterns.
- It is used dialogically—the students work in groups to make sense of it all. The curriculum includes numerous activity structures using different student groupings such

Table 3
Classroom example illustrating the design heuristics

	Low (Aligning With Traditional Instruction)	High (Aligning With Science-as-Practice)
Phenomena-based	Synthesize the fieldnotes into a list of facts about bird behavior (i.e., Finches eat tribulus seeds). Remove descriptions of how scientists collected the data to reduce the connections between the information and the natural world.	Present the fieldnotes as is so that students can picture the birds engaging in particular behaviors and include descriptions of how scientists collected the data to make the connections between the information and the natural world.
Transformable	Present the quantitative data as is but change the question such that the numerical information no longer requires transformation: i.e., ask students to describe bird behaviors or identify the year that most of the birds died.	Present the numerical data as is so that they require students to analyze the data and find patterns to answer the questions about why finches lived and died.
Used dialogically	Students work individually to answer the question and write a response that is handed in only to the teacher.	Students work in groups to evaluate and critique one another's claims regarding what caused the finch death.

that there are opportunities for students to discuss alternative interpretations and to incorporate those interpretations into their own thinking.

Consequently, this use of information supports student participation in the science practices (Reiser et al., 2001; Tabak & Reiser, 2008).

Alternatively, we could change the information and classroom context to be farther removed from these three design heuristics resulting in activities that are not consistent with science practices (see Low column in Table 3). In this case, the classroom instruction would then more closely mirror traditional science instruction. For example, we could change the presentation of the information so that it was no longer as connected to the phenomenon in the natural world. We could do this by changing the field notes to make them more general statements (i.e., Finches eat Tribulus seeds) and not showing the video. These small changes might make the information feel more abstract rather than like actual observations and measurements of a natural phenomenon. In terms of making the lesson low for transformable, a teacher could change the question so that students did not need to identify patterns or trends. For example, students could use the data in its current form to describe bird behaviors or identify the year that most of the finches died without transforming it. Finally, we could reduce opportunities for students to use the information for dialogic sensemaking through activities that focus on individual work, such as having each student write their own description of bird behaviors. In these cases, the data would not be used dialogically in that the students would not be working with their peers as they considered and critiqued multiple interpretations of the information. These relatively small changes in the curriculum could potentially impact whether students are actively participating in science practices or individually learning final form and isolated facts. Consequently, at a high level these three design heuristics support the use of scientific evidence and have the potential to serve as a lever to shift science instruction to align more closely with the science-as-practice vision.

Other Forms and Uses of Information

We acknowledge that these design heuristics offer a more narrow view of scientific evidence than used by others in the field. In helping to clarify what is meant (or should be meant) by scientific evidence use in k-12 science classrooms, we do not intend to discount the value or necessity of other types of information. To the contrary, we recognize the value of using and drawing from multiple types of information in science classrooms. In this section, we explore what this means in terms of when to call something "scientific evidence" and we consider the value of other forms of information in science classrooms for different purposes.

A straight-forward application of these heuristics suggests that maybe we should use the phrase "scientific evidence" only when we are talking about empirical data students have collected (or been given) in their science classrooms. As seen in the examples above, this type of empirical data can clearly fit the design heuristics. However, it is easy to design classroom instruction in which empirical data does not fulfill the heuristics—in which the data is presented in ways that do not connect it to a phenomenon, require transformation, or facilitate dialogic interactions (as seen in the Low column of Table 3).

Moreover, as Sandoval et al. (2014) argue, people, including scientists, use a variety of types of information when they evaluate claims. For example, when making sense of the natural world students should be accountable to both their observations of the natural world and the disciplinary knowledge (Engle & Conant, 2002)—and as such they need to incorporate disciplinary ideas (i.e., scientific principles) into their reasoning about the data. In addition, in socioscientific discussions students grapple with scientific evidence as well as other types of social, economic and moral justifications (Sadler & Fowler, 2006). For example, in discussing whether or not a dam should be built in the Amazon for hydroelectric power, students may consider information about cost and the personal impact on local tribes in addition to scientific information related to ecology and climate change (Knight & McNeill, 2015). Students can also use other information to be critical of what science is and how it is used to explain social situations, such as living conditions and health in relation to environmental racism (Mensah, 2011). For example, in learning about HIV/AIDS students can value other sources of learning outside of school, such as information about family perceptions and religious beliefs, in developing their ideas about this controversial science topic (Brotman, Mensah, & Lesko, 2011). Consequently, it is important to consider and use a variety of information from across contexts of students' lives.

Similarly, prior experiences can offer a firm ground upon which students can build new ideas regarding observations of nature (Dewey, 1933; NRC, 2007; Piaget, 1972) and provide robust foundations for understanding scientific concepts (NRC, 2007). Moreover, inclusive instructional strategies should build on students' diverse backgrounds and experiences to more meaningfully connect students with science (NRC, 2015). Explicitly discussing and building on the epistemological stances students bring to the classroom (Bang & Medin, 2010), and building on the knowledge of students' non-school lives (e.g., Calabrese Barton & Tan, 2010; Calabrese Barton, Tan, & Rivet, 2008; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001) can promote students success in science.

Thus, instead of using these design heuristics to identify the particular types of information that should and should not be used in learning environments, we offer them as rules-of-thumb that can help educators check whether they are using information (from any source) in ways that enable student sensemaking of the natural world. And, in fact, it is possible to use a variety of information sources in ways that align with these heuristics. For example, like empirical data from classroom

Table 4

Students' prior experiences in relation to the design heuristics

	Low	High
Phenomena-based	Information students have been told (e.g., "my mom told me that, when it is hot, water disappears into the sky").	Information that is based in observed experiences (e.g., "I saw a puddle in my driveway in the morning but it was gone when I got home from school")
Transformable	Asking students to describe what they have seen (e.g., what did the puddle look like).	Asking students questions that require them to interpret the experience (e.g., Were there other puddles that were still there? How were they different from the puddle that was all gone?).
Used dialogically	Experiences or information that are not shared and not easily related to other experiences (e.g., "I went to El Tatio and the water there disappears.")	Experiences that are common and enable students to question and challenge one another (e.g., "there is a puddle in my yard that takes 3 days to disappear")

instruction, personal experiences and prior knowledge can fit these heuristics, but do not always. Table 4 illustrates how different uses of prior experiences and information do and do not fulfill the design heuristics. These examples focus on elementary students considering evaporation to explain natural phenomena.

The "high" examples in Table 4 highlight how students' everyday resources can be leveraged as scientific evidence to support sensemaking about the natural world. Specifically, observing puddles is a phenomenon that is shared by numerous elementary students and the three design heuristics can help educators consider how to use this information as scientific evidence in the science classroom.

When students' personal experiences do not initially align with all three design heuristics, this information can still play an essential role in classroom instruction. Personal and social connections to students' lives can be important for student engagement and agency (Calabrese Barton & Tan, 2010; Mallya, Mensah, Contento, Koch, & Calabrese Barton, 2012). For example, the low example for Used Dialogically refers to one student bringing up El Tatio, which is a large geyser field in Chile. This example is phenomena-based for that specific child, but not for the entire class since many of the students may not be familiar with El Tatio and it is not transformable in the current state. A teacher could be supportive of that example from the individual student highlighting the importance of personal connections and that science is everywhere in our lives around us. This type of teacher move could encourage the individual student's participation, but would not enable the example to be used dialogically as information that is questioned and critiqued as a class. As such, this would still be valuable information for the science instruction, but it would not be used as scientific evidence.

Alternatively, a teacher could use the three design heuristics to integrate the student's connection to El Tatio as scientific evidence in the classroom by engaging in additional activities. For instance, by showing video of El Tatio the example would become phenomena-based for the entire class, providing data about the geyser water to analyze would enable the example to be transformable, and supporting students in questioning and challenging different explanations of what happens to the water would support it to be used dialogically. Both approaches to using the El Tatio example (personal information versus scientific evidence) have value and are appropriate in different contexts. Our goal is

for the design heuristics to provide a lens for both designing instruction a priori and for considering information that arises during classroom instruction.

Thus, we agree with Sandoval et al. (2014) claim that multiple types of information, must be attended to in science classrooms. But, we add to this claim that positioning students as knowledge builders rather than passive recipients of final form science ideas requires that they have access to information that is phenomena-based, transformable, and used dialogically. We argue that it therefore might be useful to give information that is being used in ways that are consistent with these heuristics a special name, scientific evidence. We understand that other forms of information are also key to effective science instruction, but using other terms—such as information or justifications—may help highlight the distinct role of scientific evidence and help educators to consider how to use the various forms of information in different ways in instruction.

Conclusions

As educational reform efforts are translated into classroom practice, they can be filtered by previous more traditional perspectives on teaching and learning resulting in significantly different instruction than the original intention (Cohen, 1990). Thus, we worry that the varied ways in which the term "evidence" is used in the field (e.g., Crippen, 2012; Gotwals & Songer, 2013; McNeill & Pimentel, 2010) can result in it being mapped onto a wide range of classroom activities, many of which do not support student sensemaking. In addition to classroom instruction, a similar danger arises in relation to student assessments. Developing assessments that capture the science-as-practice vision will require new approaches and be significantly different from current assessments (NRC, 2014). As such, using the word "evidence" in multiple ways may allow researchers, teachers and other science educators to believe that we are enacting the vision of science-as-practice while, in fact, we are recapitulating traditional k-12 science instruction. In this article, we argue that using the label "scientific evidence" when information is used in ways that are consistent with our three design heuristics may help educators to consistently address three common problems of practice: (i) Science as final form ideas; (ii) Data as the answer; and (iii) Isolated individuals and ideas. Future, work needs to include empirical studies that examine whether and how the incorporation of these design heuristics impacts students' opportunities and engagement in the science practices.

While we have argued for the potential of information that is phenomena-based, transformable, and used dialogically to transform k-12 science classrooms, we also recognize the necessity of many different types of information for classroom instruction. Thus, a "sensemaking bricolage," in which multiple information sources are valued and used, might best support student engagement in science. Rather than devaluing the different information sources, our argument is that using one label to refer to all of the information sources can inhibit the discussion about, and use of, each of them.

In short, we suggest three design heuristics that could potentially move classroom instruction away from problems of practice, such as final form science in which students have few opportunities for critical discourse, toward a science-as-practice vision in which students construct and critique understandings of the natural world. In order to accomplish this vision, the science education community needs to develop more refined and explicit meanings for key constructs to increase our ability to communicate meaning and develop a professional language (Osborne, 2014). In this case, we argue that refining what we mean by "scientific evidence use" in k-12 learning environments to focus on the use of information that is phenomena-based, transformable, and used dialogically may result in learning environments that more consistently enable students to meaningfully participate in the science practices.

Note

[1]The Next Generation Science Standards (NGSS) in the United States use an abbreviation system for naming the standards. For example, MS-PS1-2 is a middle school (MS) physical science (PS) standard. The numbering system, 1–2, refers to the disciplinary core idea. Specifically, in this case the 1 refers to the disciplinary core idea of "Matter and Interactions" and the 2 indicates it is the second middle school standard targeting this disciplinary core idea. All of the standards may be found on this website–http://www.nextgenscience.org

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