Design Heuristics to Enable Students Productive Use of Evidence in k-12 Classrooms

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Abstract

Research and reform efforts frequently identify evidence as an essential component of transforming science classroom activities to better enable student engagement in sensemaking about the natural world. Despite this agreement, there is disagreement about what counts as evidence in k-12 classrooms. We argue that this disagreement results in a wide range of classroom activities around evidence, including ones that recapitulate existing classroom practices. Consequently, we identify design heuristics that will help researchers and educators productively use evidence to engage students in sensemaking about the natural world by 1) selecting from the wealth of possible information the subset that should be called evidence and 2) designing classroom activities that support students in making sense of the natural world. In particular, we identify three design heuristics that could potentially transform science classroom activities to enable student sensemaking about the natural world, including: close to nature, transformable and used dialogically.

Introduction

Researchers, reform documents and standards all include evidence as playing a key role in scientific knowledge construction. For example, Kuhn and Pearsall (2000) argue that the essence of scientific thinking is characterized by "the coordination of theory and evidence in a consciously controlled manner" (p. 114). *A Framework for K-12 Science Education* (National Research Council [NRC], 2012) also highlights the importance of evidence in developing science knowledge. Specifically, the document discusses how there are common features across the domains of science. "Chief among those features is a commitment to data and evidence as the foundation for developing claims. The argumentation and analysis that relate evidence and theory are essential features of science" (NRC, 2012, p. 26-27). Moreover, when describing learning goals for k-12 science classrooms, using evidence for the construction of explanations, models and claims often arises. 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). At the secondary level, 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 studies, science education, and policy appear to agree in the primacy of evidence for students and scientists engaged in knowledge construction.

However, while evidence is frequently referenced as important for the construction and support of ideas, explanations, and claims in k-12 classrooms, it is not always clear what counts as evidence. Many studies use the term evidence non-problematically without offering a definition (e.g. Chin and Osborne, 2010; Jiménez-Aleixandre & Rodríguez, 2000; Kuhn, 2010). Other studies use empirical data as the evidence. For example, Sampson and Clark (2011) define evidence as "measurements or observations to support the validity or legitimacy of the explanation" (p. 73). McNeill's (2011) definition of "[e]vidence is data, which can consist of either quantitative or qualitative measurements (p. 795), Gotwals and Songer's (2013) definition of “Evidence consists of scientific data” (p. 602) as well as Jiménez-Alexiandre and Federico-Agraso’s (2009) description of evidence as “experimental results supporting the claims” (p. 336), all align with this focus on empirical data or observations.

In contrast, other work uses broader definitions of evidence. For example, Erduran and her colleagues (2004) refer to “a piece of evidence (data, warrants or backing)” (p. 921). This is similar to Choi and colleagues (2013) who define evidence as “data, warrant and backing of Toulmin’s components of argument” (p. 1768). In his structural model of an argument, Toulmin (1958) describes data as the foundation or information on which the claim is based, the warrant as providing the bridge between the data and the claim and finally the backing as a broader generalization, such as a scientific theory, that supports not just one, but many different warrants. Consequently, defining evidence as data, warrant or backing offers a broader description of evidence than focusing on data or empirical observations.

Other manuscripts may not explicitly define evidence, but they include examples or descriptions of coding schemes that categorize a variety of types of justifications as evidence. For example, Crippen (2012) includes a list of different sources of evidence coded for in arguments including “pre-reading”, “previously cited data”, “analogy”, “video”, and “speaker” (p. 857). McNeill and Pimentel (2010) similarly coded students’ talk as evidence if an utterance consisted of “…data or information that the student was using to argue for whether or not the climate was changing” (p. 210), which included “information such as personal experiences” and “information such as heard about it from someone else” (p. 211). Similar to this discussion of personal experiences, Oliveira and his colleagues (2012) describe evidence as “the personal narratives (informal or anecdotal evidence) presented by a student orally as grounds for their environmental arguments (p. 875). These descriptions include data, but also other types of justifications such as “warrant”, “backing”, “pre-reading”, “analogy”, “speaker” and “personal information”.

In addition, to the variety seen in science education research, the description of evidence varies across the discussion of the science practices in the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013). For example, in the description of constructing explanations the expectations for students include “Use evidence (e.g. measurements, observations, patterns)” and “Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students’ own investigations, models, theories, simulations, peer review)” (p. 61). These two descriptions of evidence in *NGSS* differ from each other and they include a wide net in terms of what counts as evidence.

The range of uses of the term evidence suggests that students are engaging in a variety of activities when they work with “evidence” in the classroom. For example, if the evidence in the classroom are empirical observations then students must identify patterns in their observations and use those patterns to construct and justify a claim. In contrast, if the evidence in the classroom are warrants then students are applying final form scientific ideas to construct and justify claims. This variety of meanings is akin to practical uses of the word “inquiry.” In the case of inquiry, teachers and researchers have applied the term to a wide range of classroom activities (Hmelo-Silver, Duncan, & Chinn, 2007). In fact, in the *Framework for k-12 Science Education* we see that “science practices” are introduced partially to address the problem that the term inquiry “has been interpreted over time in many different ways” (NRC, 2012, p. 30).

Similar to Goldman and Scardamelia’s (2013) argument that lack of clarity around the words “source” and “document” lends itself to significant confusion in research and classrooms, we argue that the vague and contradictory uses of the term evidence could result in confusion on the parts of teachers, researchers and other science educators as we try to support and characterize students' work in the science classroom. For example, when focused on socioscientific issues, using the term evidence to mean a broad range of information types might lend itself to what Bromme and Goldman (2014) call the "blurring of the scientific and the nonscientific aspects of problems" (p. 65), making it difficult to determine which aspects of the proposed solutions are debatable and which are not. In addition, determining "what counts as scientific evidence" (Sinatra, Kienhues, & Hofer, 2014, p. 126) is a key part of making sense of science and reconciling different explanations of the natural world. We would add that, we cannot determine what specific information should count as evidence in classrooms until we have a shared understanding of what the word means.

Moreover, using the term evidence in vague ways may enable us to believe that we are enacting the vision of science practices laid out in the NGSS while, in fact, we are recapitulating current classroom instruction. That is, the *Framework for k-12 Science Education* (NRC, 2012) lays out a transformative vision of science education—that was reified by the NGSS (NGSS Lead States, 2013)—in which students are collaboratively making sense of evidence to construct understandings of the natural world. In this paper, we argue that some uses of the word evidence align with this vision of science education while others do not. If the term evidence is mapped onto to a wide range of classroom activities, we may diminish the potential transformative opportunity of this new vision of science education.

While one response to the question of what evidence should mean in k-12 classrooms is to turn to the scientific community and match scientists' use of the term, we argue that we should focus on what we want the evidence to enable students to do in k-12 science classrooms. We argue this partially because there is not one clear definition of evidence for the science community. Furthermore, as argued by Russ (2014), students' activities do not need to recapitulate those of scientists, but they should enable students to engage in the work of making sense of the natural world. From this perspective, the question should be: What are the most productive ways of using evidence to support science learning in k-12 classrooms?

Consequently, in this piece, we develop design heuristics for the productive use of evidence that support students in k-12 science classrooms in ways that align with the transformative vision laid out by the NRC (2012). These design heuristics consider what counts as evidence as well as how that evidence is used within the classroom. As we will discuss in more detail, it is not just the evidence that is important, but also the context of evidence use that potentially impacts k-12 student learning.

Sensemaking about the Natural World

To develop design heuristics for supporting k-12 students' productive use of evidence, we first consider the goal of science. Again, we are not working to align our definition or use of evidence with that of the scientific community but we are, instead, working to support students in engaging in the overarching goal of science. However, this work with students does build off the goal of science.

The fundamental goal of science is: *sensemaking about the natural world* (Osborne, 2010; Russ, 2014). That is, science is linked to nature; however, science is not just copying, reflecting or describing nature. Rather, scientists engage in considerable intellectual and collaborative struggles to interpret and explain natural phenomena (Driver et al., 1994; Ford, 2008). In this section, we unpack the *sensemaking* and *the natural world* aspects of the overarching goal of science to better understand this goal and how evidence might be used in k-

12 classrooms to enable students to work towards it. We begin with discussing the natural world as we see nature as grounding the activities of science. Then we focus on the sensemaking, which considers the activities or practices of scientists. This understanding of the overarching goal of *sensemaking about the natural world* then drives our development of design heuristics for the productive use of evidence in k-12 science classrooms.

About the Natural World

Nature, or the natural world, is an essential characteristic of science that undergirds the goals of the scientific enterprise. We build on the work of Michael Ford who makes the case that nature is essential for science and is part of what distinguishes science from other disciplines and everyday practices. Ford argues that nature herself is a crucial third party and that "In science, claims are accountable to the way nature actually behaves. Nature is what it is, despite our ideas about it. So because the aim of science is to explain nature, and because nature is indifferent to our beliefs about it, nature is the final arbiter of debates in science." (Ford, 2008, p. 407-408) Ford further explains the difference between everyday and scientific claims is this connection to nature in that, "The informational content of scientific claims, unlike everyday claims, is comprised by the explicit connection to nature and what function that connection serves toward the valued aim of the practice more broadly" (p. 416).

Similar to Ford (2008), we argue for the importance of nature by drawing from the work of science studies and the philosophy of science. A number of scholars in these arenas refer to the importance of the natural world in the work of scientists. For example, Harré (1986) discusses that scientists construct scientific knowledge using an empirical basis from the natural world, even though there is no one truth about that world. Rouse's (1996) work on science practices describes how the actions of scientists require an ongoing engagement with the world. Even in Latour's (1999) work, in which he argues that science is "…no longer a mind-in-a-vat looking through the gaze at an outside world" (p. 16), the natural world still plays an important role. In Latour's argument, scientists are a part of that natural world, instead of cut off from it, allowing a multiplicity of possible interpretations.

Moreover, when there are major shifts in understanding in the scientific community, these shifts are also linked to nature. For example, Kuhn (1962) argued that paradigm shifts occur in science when an anomaly about nature arises. He argued that "Discovery commences with the awareness of anomaly, i.e., with the recognition that nature has somehow violated the paradigm-induced expectations that govern normal science" (p. 52-53). He suggests that scientific discoveries are driven by new and unsuspected phenomena in nature. As such, the practice of science is continually connected to nature; however, this relationship is mediated by scientists and the scientific community making sense of nature.

Sensemaking

This connection to the natural world is not a replication of nature. 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). Thus the goal of science is not just to describe the natural world, but to make meaning of those observations in ways that are significant. Consequently, science is more than the work of describing nature. Indeed, 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; Sandoval & Millwood, 2005; Salmon, 1978).

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

> 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 (Bell, Bricker, Tzou, Lee, & Van Horne, 2012; Duschl, 2000; Krajcik, Berger, & Czerniak, 2002; Windschitl, Thompson, & Braaten, 2008). Thus, we see that the work of science entails interpreting observations of nature in order to make sense of them—to understand how and why nature works in the ways that it does.

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 (D. Kuhn, 1993; T. Kuhn, 1962; Longino, 1990; Osborne, 2010; Pera, 1994; Rouse, 1996). 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 individuals communally construct and critique possible scientific ideas—finding possible errors in one another's work to collaboratively develop progressively more valid and reliable interpretations.

Pera (1994) brings together these aspects of the scientific endeavor, describing the role of nature within this collaborative sensemaking. He offers a dialectical model of science in which scientific knowledge is constructed through argumentation between scientists and nature:

> The dialectical model is different; it requires three players: a proposer who asks questions, nature that answers, and a community of competent interlocutors which, after a debate hinging on various factors, comes to an agreement upon what is to be taken as nature's official voice. In this model nature does not speak out alone. It only speaks *within* the debate and *through* the debate. (p. 11)

In this dialectical model, nature plays a fundamental role; however, the social elements remain. In this depiction of science, the goal is to understand or make sense of nature, but "truth" is no longer the final outcome because the current understanding of nature is always transformed by the other two players (i.e. proposer of ideas and the scientific community) in the dialectical model. As such, while scientists are working to make progress and develop progressively more accurate explanations of nature, there is no known "right" answer. Instead, they work collaboratively constructing and critiquing (Ford, 2008) one another's ideas in order to become increasingly consistent with nature—with the data. In this way, scientific knowledge building occurs through a dialogic interaction between the scientists engaged in the sensemaking and nature itself.

Design Heuristics for Scientific Evidence in K-12 Classrooms

Given this understanding of the scientific endeavor, when we return to the question of identifying the most productive ways of using evidence to support science learning in k-12 classrooms, we must consider how evidence should be used within classroom contexts to enable students to accomplish this goal of collaboratively making sense of the natural world. 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 1) selecting from the wealth of possible useful information the subset that should be called evidence 2) designing classroom activities that support students in making sense of the natural world. As illustrated in Figure 1, we suggest that information that is both close to nature and can be used for collaborative sensemaking is the most productive scientific evidence for k-12 classrooms.

We begin with two caveats to the scope of our work. First, in helping to clarify what is meant (or should be meant) by the word evidence, we do not intend to discount the value or necessity of other types of information. To the contrary, we recognize that claims are warranted using a variety of different types of justifications in science (Sandoval & Cam, 2011; Sandoval, Sodian, Koerber & Wong, 2014). 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. Similarly, prior experiences can offer a firm ground upon which students can build new ideas regarding new observations of nature (Dewey, 1933; NRC, 1999; Piaget, 1972). In addition, in socioscientific discussions students grapple with scientific evidence as well as other types of social, economic and moral justifications (Sadler & Fowler, 2006). In each of these cases, the disciplinary ideas, prior experiences, and other justifications are vital to the students' sensemaking about nature but we argue that the information should not be called scientific evidence—that doing so reduces the potential transformative power of that term. Thus, as seen in Figure 1, we recognize the wealth of available, relevant, and useful, information that comes from within and outside of the classroom context. Our argument is simply that it should not all be called *scientific evidence*.

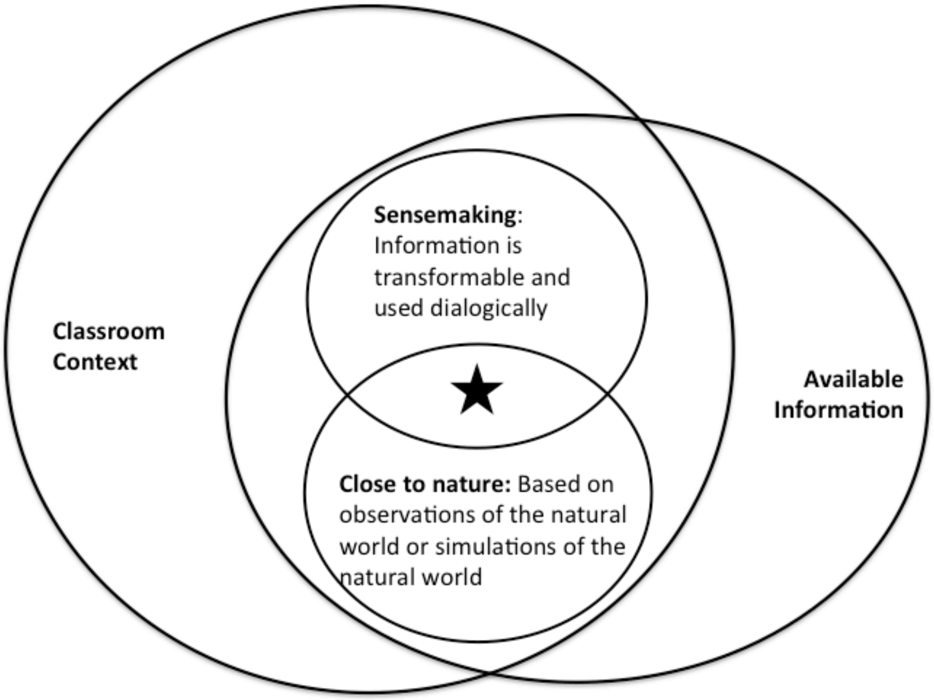

Figure 1: Information that enables the productive use of evidence in k-12 science classrooms

Our second caveat pertains to the scope of the design heuristics. As seen in Figure 1, we understand the design heuristics as occurring within the broader classroom context. As such, the classroom norms regarding the students' roles, goals, and behaviors; the teacher's role; the activity structures in which they engage; the type of information that is available; and additional sociomaterial factors all influence whether and how students engage in science activities. In this article we focus on those factors that pertain directly to the selection and use of evidence.

In the next section, we define three heuristics (i.e., close to nature, transformable, used dialogically), provide rationales for how they support student sensemaking about the natural world, and offer specific examples. These design heuristics can inform the development of learning environments that enable students to engage in the overarching goal of science (Russ, 2014): sensemaking about the natural world.

Close to Nature

Science instruction is often criticized as focusing on the memorization of discrete concepts, facts and laws, which support students' perception of science as a final form that does not change over time (Duschl, 1990). For example, in the United States, teachers rarely engage students in the practices of science, but rather present science content as disconnected facts, algorithms and definitions (Roth & Garnier, 2006). Recent reform efforts (NRC, 2007; NRC, 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 in diverse contexts as they engage in science practices such as developing models, analyzing data and constructing explanations. These models of science literacy focus more on what students should be able to do and less on what facts they know (Sandoval, et al., 2014).

Instead of just presenting students with abstract science concepts, big ideas in science need to be explicitly linked to natural phenomena. 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) 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 engaging with specific examples, students can experience science learning as sensemaking about the world around them, rather than as memorizing facts. Experiences that are close to nature - interacting with natural phenomena - are a goal for scientists and learners alike.

Thus, we argue that *close to nature* is an important design heuristic, not only because it aligns with the overarching science goal of sensemaking about the natural world, but also because it could potentially support student learning by shifting k-12 science instruction away from final form science. By saying that evidence should be *close to nature* we are arguing that the information labeled as evidence should be recognizably related to the phenomenon under study. Thus, evidence is close to nature when it consists of empirical data (e.g. qualitative observations or quantitative measurements) about the natural world (see Table 1). This heuristic is in contrast to Sandoval and colleagues' (2014) argument that data (or empirical observations of the natural world) are "not the only kind of evidence people, including scientists, consider when they evaluate claims" (p. 140). As stated earlier, by using scientific evidence to mean a particular type of information—empirical data about the natural world—we do not mean to suggest that the other information people use is unimportant. Thus, we agree with Sandoval and colleagues' claim that the other information sources must be attended to. We are simply arguing that it is pedagogically useful to give a special name to that information that is close to nature—that doing so helps to position students as knowledge builders rather than passive recipients of final form science ideas.

Table 1: Design Heuristics for the Use of Scientific Evidence in K-12 Classrooms

Goals of Science	**Design Heuristic**	**Description of Heuristic**
About the natural world	Close to nature	Evidence is close to nature when it consists of empirical data (e.g. observations or measurements) about 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).
Sensemaking	Transformable	Evidence 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	Evidence 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.

In order to be close to nature, students do not necessarily have to collect evidence themselves. Rather, the empirical data 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 while 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 engage in phenomena that they cannot 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).

Although second-hand data offers important learning opportunities, unfortunately students can accept second-hand data with little questioning, instead viewing it as authoritative more like static facts or truth (Hug & McNeill, 2008; Palincsar & Magnusson, 2001). Consequently, although students do not need to collect the data themselves, the information should be directly linked to the natural world to support student sensemaking about nature. This is in contrast with an activity in which students are provided with lists of statements or descriptive text that is not explicitly linked to the natural world. For example, Osborne and his colleagues (2004) include an example activity in which students engage in argumentation about light using provided statements such as “Light travels in straight lines.” and “Sunglasses are worn to protect our eyes” (p. 1003). Although they engaged students in the social dimensions of argumentation in which they critique and question each others’ ideas, we are concerned that something is missing in this activity: while the teacher is not lecturing facts to students, students could still view science as discrete facts or definitions because their sensemaking is occurring around lists of such concepts. We argue that lists of statements or text not linked to phenomena, may not be as productive for helping students develop epistemologies and practices that align with the goal of making sense of the natural world. In short, we argue that regardless of whether the evidence is first hand or second hand, that it should consist of data, such as observations or measurements, which are explicitly linked to the natural phenomenon under study.

Engaging Students in Sensemaking

In addition to providing access to information that is close to nature, engaging students in the science practices rather than the memorization of final form science ideas means that students must be engaged in sensemaking. Individuals learn by interpreting their observations not through reception of authoritative facts (e.g., Edelson, 2001; Kolodner et al., 2003; NRC, 1999; Scardamalia & Bereiter, 1991; Schank, 1982). As stated by Kitchener (1992): “what is known is constructed or generated, since incoming data are processed and transformed” (p. 125). Thus, sensemaking in science—the interpretation of observations of nature—is a goal for scientists and learners alike. This process can support students in developing a deeper understanding of scientific explanations and models.

As Scardamalia and Bereiter (2006) argue, “there are substantial similarities between deep learning and the processes by which knowledge advances in the disciplines” (p. 97). Thus, it is unsurprising that, like scientists, students engage in sensemaking not by constructing knowledge individually 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). 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; Osborne, 2010; Marlene Scardamalia & Bereiter, 1994; von Aufschnaiter, Erduran, Osborne, & Simon, 2008).

Furthermore, students can interpret “data as factual rather than constructed and open to interpretation” (Sandoval & Çam, 2011, p. 401). This suggests that focusing on close to nature alone will not necessarily transform classroom practices to align with the vision found in the Framework because even when given empirical observations, students can see this data as final form instead of open to questioning and critique. Consequently, it is important for students to engage in activities in which they transform and evaluate evidence. Without these opportunities, students are likely to continue framing science as an opportunity to memorize final form facts (be they empirical evidence or statements of scientific principles) rather than as a time to engage in sensemaking about the natural world.

Thus, the question facing our development of design heuristics is: what are the characteristics and uses of evidence that will enable students to collaboratively make sense of that evidence? With this question in mind, we propose two characteristics for enabling sensemaking with evidence in k-12 classrooms: 1.) The evidence must be transformable if students are to make sense of it and 2.) The evidence must be used dialogically. We unpack these characteristics in the following.

Transformable. By transformable, we mean that, when determining what information should be scientific evidence in k-12 classrooms, we must consider the degree to which the information in question requires and enables the sorts of transformations depicted by Duschl (2000). That is, the information must enable students to engage in sensemaking by requiring that students select what information to use, manipulate it to find patterns, and evaluate the fit between those patterns and their expected claim. To be productive evidence, the information cannot be an answer to the question being asked without that transformation.

For example, when asking students to construct an argument about the role of humans in climate change, a teacher could give students access to databases such as those with data over time about greenhouse gas emissions from industry, atmospheric temperatures and carbon dioxide concentrations. Alternatively, the teacher could supply statements of facts 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. However the second example that includes the statements of facts does so without transformation—you use the statements as a whole piece of information or not at all. In contrast, the first 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 the information is transformable can only be determined in relation to the question being asked. For example, one could give students a database with atmospheric temperatures and carbon dioxide concentrations and ask them to identify the year with the highest atmospheric temperature. This would require searching the database, but would not require transformation of that information. Consequently, it is not just what information is used, but the relationship between that information, the question being asked and the structure of the activity, which impacts the potential transformability of the information in k-12 classrooms.

Used Dialogically. The next heuristic of evidence that supports students' collaborative sensemaking is that the information must be used dialogically to support meaning making. By used dialogically, we mean that evidence is used and critiqued in a social process with other individuals (Jiménez-Aleixandre & Erduran, 2008). That is, the purpose of evidence in collaborative sensemaking is to provide grounds upon which claims can be made, justified, and refuted (van Eemeren, Grootendorst, Johnson, Plantin, & Willard, 1996; Toulmin, 1958). A focus on social sensemaking during which students construct and critique ideas can discourage singular forms of sensemaking in which new evidence is only used to confirm one's existing idea (Ford, 2012). Rather students take a critical perspective and probe evidence considering multiple claims. 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, Driver & Osborne, 1999). Thus, this design heuristic focuses on activity structures and classroom norms that support the development of a classroom community in which students are substantively interacting with each other using evidence.

A teacher could structure instruction around the same scientific question and data in different ways, which impacts whether or not the evidence is used dialogically. For example, a lesson could 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 both in class investigations and second-hand data from athletes and non-athletes including variables such as amount of exercise, lung size, mitochondrial protein, and heart rate. In order to support the students in using the evidence dialogically, the teacher could explain to the class that they will be engaging in a science seminar, which is a student run conversation with the purpose of using everyone's ideas and questions to build a stronger understanding. To prepare for the science seminar, the 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 engage in a dialogic discussion in which they question and critique each other's ideas about the evidence, 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 close to nature and require students to transform the data, but it would not engage the students in social interactions in which they collaboratively make sense of the evidence.

In order to support the dialogic use of evidence, it is important to consider not only the activity structure, but also the roles of the teacher and students within the activity. Dialogic interactions between students are not the norm in science classroom (Newton, et al., 1999). Even when enacting curriculum explicitly designed to support these types of student interactions, teachers can adapt the lessons to more traditional teacher led instruction (McNeill, González-Howard, Katsh-Singer, Price & Loper, 2013). Consequently, it is important to consider the activity structure in relation to the broader classroom context and support teacher and student roles that enable student collaborative sensemaking about scientific evidence.

Illustrating the Design Heuristics and the Importance of Context

In designing learning environments that engage students in making sense of the natural world—and researching student engagement towards this goal—it is important to understand that whether information is being used as productive evidence depends on the context. For example, as seen above, the same information might be considered transformable or not transformable depending on how it is presented and the question it is being used to explore. 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 student engagement with evidence, we must examine the whole context in which the evidence is being used not just the piece of information being labeled as evidence.

To illustrate this point, we take an example from Reiser and colleagues' (Berland & Reiser, 2009; Reiser et al., 2001) research. In this case, students are investigating a database of information about the Finches on the Galapagos Islands in the mid-1970s. The students are using this database to figure out why the majority of the Finches died in 1976-77 and why some were able to survive the catastrophe.

The database (beguile.northwestern.edu) provides students with: detailed fieldnotes about the finches that say things like: "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 beaksize, wing span, height and weight for numerous years before and after 1976; and quantitative and qualitative data about the environment, including other organisms and weather patterns. Before investigating the database, students watch a video showing how the scientists gathered this information.

Using the characteristics identified above, we argue that the information offered through this learning environment is productive evidence for k-12 classrooms because:

- It is close to nature – 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 being used dialogically–the students work in groups to make sense of it all. The curriculum includes numerous activity structures using different student groupings such that there are opportunities for students to discuss alternative interpretations and to incorporate those interpretations into their own thinking.

Alternatively, we could change the information and classroom context to be farther removed from sensemaking and close to nature resulting in a less productive learning environment for students (see Table 2). For example, we could change the presentation of the information so that it supported sensemaking but not a connection to the natural world. One could do this by changing the field notes to make them more general statements (i.e., Finches eat Tribulous seeds) and not showing the video. These small changes might make the information feel more abstract for students rather than observations or measurements of a natural phenomenon.

Similarly, we could change the relationship with student sensemaking either in terms of transformable or taken as shared. In terms of making the lesson low for transformable, a step in this direction would be to change the question so 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. In addition, we could reduce opportunities to use the information to engage in dialogic sensemaking through activities that focus on individual work, such as having each student write their own argument. 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 evidence.

Table 2: Classroom Example Using the Design Heuristics

		Close to Nature	
		Low	High
Sensemaking	High	*Transformable*: Present the numerical data as is such 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 in groups to evaluate and critique one another's claims regarding what caused the finch death.	*Transformable*: Present the numerical data as is such 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 in groups to evaluate and critique one another's claims regarding what caused the finch death.

	Close to nature: 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.	*Close to nature*: Present the fieldnotes as is such 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.
Low	*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. *Used dialogically*: Students work individually to answer the question and write a response that is handed in only to the teacher. *Close to nature*: 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.	*Transformable*: Present the data as is but change the question such that the numerical information no longer requires transformation: ask students to describe bird behaviors or identify the year that most of the birds died *Used dialogically*: Students work individually to answer the question such that there is no collaborative sensemaking. *Close to nature*: Present the fieldnotes as is such 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.

Conclusion

Science practices are dynamic not only in that context matters, but they are also open to reinterpretation by the scientific community and semantic drift (Rouse, 1996). Consequently, we are not arguing for one definition of scientific evidence that characterizes all practices of scientists. We leave those disputes to those more engrossed in the field of science studies. Rather we focus on characteristics of evidence in use that could engage students in constructing knowledge about how and why the natural world works (Russ, 2014). With the recent push for science practices in reform documents (NRC, 2012) and national standards (NGSS Lead States, 2013), the idea of evidence has the potential to play a greater role in k-12 classrooms and could be a leverage through which we transform classrooms to better enable student sensemaking. However, we worry that with the multiple uses of the term evidence in the field (e.g. Gotwals & Songer, 2013; Choi et. al., 2013; Crippen, 2012) that evidence can be mapped onto a wide range of classroom activities, including ones not intended by recent reform efforts. 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). Much as we see with the word “inquiry,” 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 practice laid out in the NGSS while, in fact, we are recapitulating current k-12 science instruction.

Consequently, we suggest three design heuristics that could potentially move classroom instruction away from final form science in which students engage in minimal critical discourse towards a new vision of science instruction in which students construct and critique understandings of the natural world. Specifically, we argue that designing learning environments in which information is – close to nature, transformable and used dialogically – may enable students to engage in the fundamental goal of sensemaking about the natural world.

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