Modeling the Construction of Evidence through Prior Knowledge and Observations from the Real World

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Abstract: Evidence is key to many scientific practices including argumentation. For learners engaged in scientific practices, we aim for them to recognize scientific evidence from observations in the natural world. Here, we provide an early depiction of evidence construction, namely *how* evidence is constructed from one's prior knowledge and one's observations. We illuminate instances of teachers constructing evidence while engaged in a professional development workshop where they are tasked to reconstruct the geological history of a national park. We illustrate four cases, some of which involve the successful construction of evidence and some of which involve embedded challenges with constructing evidence, such as difficulties with background knowledge and individuals "seeing" different information in the same phenomena. This analysis illustrates the role of prior knowledge in scientific practices that rely on evidence construction in field-based complex environments.

Introduction
A central focus of the Next Generation Science Standards (NGSS) is engaging students in the learning of scientific practices, such as argumentation and modeling. Here we focus on evidence construction, which we argue is important for many of these scientific practices. Science education research discusses the importance of evidence in the scientific process and in students' engagement in these practices in the classroom. However, less frequently discussed in this literature is research on *how* learners develop evidence from their immediate experience of phenomena. Possibly this issue is overlooked because often learners that are engaging in scientific practices are provided with evidence a priori. Here we use theoretical machinery from coordination class theory (diSessa & Sherin, 1998) to show how learners constructed evidence from their prior knowledge and observations of the world. The learners were middle school earth science teachers who observed the geology of an area and constructed evidence for the relative ages of the rocks and other features based on their observations and prior knowledge.

Evidence and Evidence Construction in Scientific Practices
Evidence is at the core of knowing and doing in science. No idea or explanation can be accepted if it fails to square with the "facts of the matter." Ironically, the origins of evidence construction—where the "facts" come from—are complicated. Fundamentally, evidence consists of straightforward observations dependent upon the five senses (i.e., perception). However, what is perceived depends upon the knowledge and expectations of the observer (Chalmers, 1999). To put it another way, the "facts" of any "matter" are never directly apprehended; they are constructed in the mind of the observer. Science educators acknowledge this fact along with its implications for learners engaged in scientific inquiry. For instance, Duschl (2003) described how learners begin with observation and end with explanation as they move through a series of transformations on an evidence-explanation continuum. The learner begins with the transformation from *data to evidence*, then goes from *evidence to patterns and models*, and finally moves from *patterns and models to explanations*.

Science education standards (e.g., NGSS, 2013) emphasize that evidence is paramount to student understanding of science. The 2007 National Academy Press report describes that students who understand science should be able to generate and evaluate scientific evidence (Duschl, Schweingruber, & Shouse, 2007). In the Framework for K-12 Science Education, a commitment to evidence is foundational for developing further claims and for engaging in many scientific practices, such as explanation, argumentation, and modeling (NRC, 2012). When constructing scientific explanations, using appropriate evidence is key for those explanations (McNeill & Krajcik, 2007). In argumentation, evidence is one of the pillars of the widely used Toulmin Argumentation Pattern (e.g. Erduran, Simon & Osborne, 2004). In modeling, the science content and relevant data is centrally important because a model needs to be *of* something (Lehrer & Schauble, 2006).

Construction of evidence from interactions with the natural world has rarely been the focus of research on the use of evidence in science education. In many studies, evidence has been provided to students as the starting point for the instruction process. Studies of this type have shown that students have difficulties both using appropriate evidence (McNeill & Krajcik, 2007; Sandoval, 2003) and understanding what counts as evidence (Sadler, 2004). These challenges are also prevalent in adults (Kuhn, 1991). McNeill and colleagues (McNeill et al., 2006; McNeill & Krajcik, 2007) conducted a series of studies in which learners constructed scientific explanations using claims, evidence, and reasoning. The data students used as evidence in their explanations were derived from either chemistry investigations or observations or reading materials. Bell and Linn (2000) presented the results of a student debate about how far light travels. The debate was scaffolded through an argument building software called SenseMaker where students were presented with 13 pre-existing items of evidence, but they had the option of adding unique evidence. From another perspective, research using a technology supported curriculum called Explanation Constructor had students construct and evaluate scientific explanations for natural phenomena, mainly the natural selection of finches in the Galapagos Islands (Sandoval, 2003; Zembal-Saul et al., 2002). Built into the curriculum was a database of information such as field notes about bird behavior and environmental factors (e.g. numbers of plants and animals in a given season). The students could query the data, and the software automatically generated graphs to scaffold the data analysis being easily connected to explanations. Studies like these have led to a line of research that focuses on developing and implementing curricula where students are asked to reason with evidence and ground their explanations and arguments in evidence (e.g. Zembal-Saul, et al., 2002).

Studies in the broader learning sciences literature have grappled productively with how learners might interact with phenomena to construct evidence. Goodwin (1994) proposed that "nature is transformed into culture" (p. 607) through processes of coding, highlighting, and representation. His point was that these processes, involving interactions with people and tools, organized learners' perceptions of nature to develop categories of importance needed for "practices of seeing" (p.608). He illustrated the processes with archeology graduate students learning to distinguish and interpret different colors and patterns in dirt. In an example of highlighting, an archeologist drew a circle around an area of colored soil to indicate to others where an ancient wooden post had been. Coding occurred when students learned to compare the colors of dirt on a trowel to those of a standard color chart, where the color of dirt on the trowel never quite matched any color on the chart. In a review of the literature, Mogk and Goodwin (2012) described how geology graduate students in a field camp learned to "construct and 'read' the story of the Earth" (p. 145). The authors described how students, guided by their professor, scrutinized minute changes in the size, shape and distribution of rock to select and make crucial "first inscriptions" (p. 145). However, the authors did not go deeply into how evidence construction occurred except to make the general point that it was mediated by the professor's guidance, tools, and interactions with peers.

Evidence construction in this type of natural world setting is important because there is a wide-ranging space of potential evidence that a learner needs to sift through and that sifting process may support learning. Geologists have long recognized the importance of field experience in geology education. Thus, it is not surprising that researchers in geocognition have begun studying learning in the field (e.g. Petrocovic, Libarkin, & Baker, 2009).

Studies in the literature on expertise have shown how experts construct evidence. For experts, constructing evidence is nearly automatic because they are so familiar with the phenomena they encounter. That is, experts' evidence is largely pre-constructed, in memory. This point is illustrated by Eberbach and Crowley (2009). Reviewing the work of Alberdi, Sleeman and Korpi (2000), Eberbach and Crowley described how botanists compared features of plants. The botanists fluidly identified the relevant parts of plants and their features in order to identify similarities and differences between different organisms. Similarly, Knorr-Cetina and Amann (1990) presented an ethnographic study of how visual evidence was constructed by a community of molecular geneticists who were discussing a film. The translation of this visual film into data and then evidence was again a fluid process involving jointly produced talk by the scientists as they were interacting with each other and the object in question. However, needed are studies that illuminate how this process of constructing evidence unfolds with learners.

Our data was collected as part of a multiple-day geologic field experience in which learners made observations of the bedrock, and those observations had the potential to be constructed into evidence for complicated historical events. The current study builds off geocognition literature on learning in the field by describing learners' construction of evidence as they developed models of historical geology. We present data from a teacher professional development (PD) workshop where participants were engaged in model development and model revision in the field. Although a PD workshop is not inherently a naturalistic setting, this course primarily occurred outside in a complicated field geology environment where there was a large span of phenomena that the teachers could focus on while constructing evidence. Thus, our research setting was a step toward the type of real world settings that have been less frequently focused on in the broader science education literature. Our research goal was to begin conceptualizing learning in this complicated field geology environment, where there was a wide range of approaches and reasons for how evidence was constructed.

The contribution of this paper is to show how the evidence construction process unfolds from the learners' sensory perception of phenomenon in natural settings to their conception of the phenomena as evidence in relation to a claim. Both perception of phenomena and conception of evidence are inherently knowledge-dependent (Chalmers, 1999; Metz, 2000), therefore, our model focuses on learners' knowledge as they construct evidence in this complex environment.

Data Collection Context

Data were collected during a three-day (17 hours) PD workshop for experienced sixth grade earth science teachers. The workshop focused on evidence-based modeling activities to support the implementation of the *NGSS* (2013). The workshop focus was reconstructing the geological history of the Schoodic Peninsula in Acadia National Park. During the workshop the teachers made observations and drew surface maps and cross-sections of the bedrock at three locations, while learning about geological principles. Over the course of the workshop, the teachers developed a series of increasingly sophisticated drawings, or models, of the Schoodic Peninsula at three points in time based on the geological features they observed. The oldest feature they observed was the granite bedrock of the area (~400 million years). Next were a series of ~200 million old diabase dikes. Diabase, an igneous rock similar in composition to basalt, forms as magma flows into fissures in surrounding rock (granite in this case) and cools. Figure 1 shows several teachers sitting on a large dike. Figure 2 shows a series of small dikes that are a few centimeters wide. The third set of features that teachers observed were remnants from the most recent glaciation (~20,000 years ago) including glacial erratics, which are rocks that have been transported by glaciers, and markings in the bedrock, such as chatter marks, striations, and cracks. Figure 3 shows an example of the striations that the teachers observed. Teachers' models from the first day of the workshop focused on diabase dikes and glaciation at Schoodic point, which is on Schoodic Peninsula. The models from the second day were more complicated due to additional observations of chatter marks, striations, and cracks from a new location on the same peninsula, Fraser point. The models on the third day were even more sophisticated as teachers added information about tectonic plates from geologic maps and simulations. The workshop instructor was one of the authors and there were two geologists and three education researchers, including another author, supporting the instruction and data collection.

Data consisted of video and audio recordings from both fieldwork and classroom instruction. Additionally, the data corpus included all drawings and notes created by the teachers and researchers field notes. Initially we open coded the data (Charmaz, 1995). Open coding led to focused codes related to geological content (e.g. diabase dikes, glacial erratics, chatter marks) and aspects of argumentation (e.g. rebuttal, claim).

Figure 1. Several of the teachers sitting on a diabase dike.

Figure 2. An example of a diabase dike.

Figure 3. An example of glacial striations on diabase.

Model of How Evidence Was Constructed from Observations of the Real World

We use coordination class theory to show how learners constructed evidence in natural settings from the interaction of human sensory data with prior knowledge. The use of coordination class theory was motivated by recognition that during the PD workshop the teachers explored a set of geological features which many of them had seen before (all teachers lived in the area and had visited the park in the past, many had even participated in field trips led by park naturalists), but teachers also commented about seeing new things ("It looks the same, but I'm noticing more though.") since the last time they visited the location. These comments raised questions about "seeing." What did it mean to "see" new things even if you have literally "seen" the same thing before? How did what someone "saw" relate to the geological models they constructed?

Coordination class theory is an outgrowth of Knowledge in Pieces, which is an epistemological framework and analytical perspective on learners' prior knowledge (diSessa, 1993; diSessa & Sherin, 1998). One research direction focused on the nature of knowledge structures that underlie conceptual understanding. Coordination class is a model of a particular type of concept that is common in physics. Prototypical examples include force and acceleration (diSessa & Sherin, 1998). Recently, the coordination class model has been applied to other concepts, including probability (Wagner, 2006) and oscillatory motion (Parnafes, 2007). Coordination classes were originally built to capture conceptual learning, but here we apply a subset of the theoretical machinery to evidence construction. We present what diSessa (1991) referred to as a mini-model, which is a type of localized theory, aiming to get at the essence of a phenomenon and address "why questions." In this case, we present a model for how teachers constructed evidence, based on their in-the-moment, observations of bedrock geology, in order to support subsequent claims.

According to coordination class theory, there are phenomena in the world that have the potential to be "seen"—they can literally be *read out* [observed] of a situation. To read things out of a situation one needs a strategy, or a way of perceiving the phenomenon that determines what is attended to. This is known as a *readout strategy*. The observation generated by the readout strategy is the readout. There are many possible readout strategies, and they can involve perception with the eyes or other senses. The *causal net* is the entire knowledge system, composed of both knowledge and strategies that will help determine how the information—that is momentarily read out—relates to the overall knowledge system. When one uses readout strategies to read out [interpret] information in the world there is an instantaneous interaction between the information that is read out and specific *knowledge pieces* within their causal net. This instantaneous interaction is referred to as an *inference* as it functions as the link between the observable information and the determination of things that are not as easily observable. One or many inferences together become *evidence*. This model can be illustrated with an example: suppose an individual is making observations of a diabase dike that is cross-cutting granite while constructing evidence for a claim about the granite being older than the diabase. The individual might read out specific information about the granite cracking in linear patterns and the darker diabase exhibiting a circular or swirling pattern within those cracks (see Figures 1 and 2). Instantaneously, the information that is read out might be combined with prior knowledge into a subsequent inference about the molten diabase having flowed into the existing cracks in the solid granite. This inference (possibly combined with other inferences) then might function as evidence for a claim about the diabase being younger than the granite because the granite would have had to already exist when the diabase intruded. However, it is also possible that an individual might only read out the type of rock, granite or diabase, and then not go any farther to connect what they observe with any scientific claims. In that case they have made observations of the rocks, but they have not constructed evidence. Another possibility is that an individual might read out information and decide that it is unrelated. For instance, an individual might read out that lichen is growing on the rock, but their prior knowledge would guide them to instantaneously decide that lichen, which is biological, is unrelated to the claim about the rocks relative ages. In the moment their prior knowledge would attune those readouts such that some become inferences that then turn into evidence for subsequent claims and irrelevant readouts would be discarded.

We used coordination class theory to illustrate four cases of teachers constructing evidence from bedrock as they attempted to reconstruct geologic history of Schoodic Peninsula. In the first case, the teachers focused on cracks in granite where diabase crosscut the granite. This case illustrates how the teachers successfully constructed evidence for the relative ages of the rocks—granite being older and diabase being younger—based on the read out information as it is connected to their prior knowledge and subsequence inferences. Similarly, the second case illustrates a teacher successfully coordinating multiple sources of evidence into a series of claims. In the third case, teachers focused on marks in the bedrock that may or may not have been chatter marks. The teachers lacked sufficient background knowledge to make conclusive inferences about the chatter marks, and therefore were hindered in constructing evidence for glaciation. In the fourth case, several teachers discussed whether or not diabase dikes extended below the surface. Individual teachers had different answers to this question depending on what they read out in the situation. This case illustrates that individuals read out different information from the same phenomena, and these different readouts could lead to the same phenomena being construed as evidence for different claims. The third and fourth cases were similar as both identify challenges in constructing evidence.

Case I: Successful Evidence Construction about Diabase Dikes Crosscutting Granite

This is a case of unproblematic evidence construction as a teacher was able to draw on her prior knowledge with relative ease. This case came from the first day of the professional development workshop when two teachers, Barbara and Naomi spent 20 minutes discussing diabase dikes. Instructionally, we aimed for the teachers to first, see the diabase dikes as cutting through the granite (Figures 1 and 2) and second, use the geological principle of cross-cutting relationships to deduce that the diabase was younger than granite. Teachers were asked to construct surface and cross-sectional maps to support their thinking.

The teachers were reading out information about the granite cracking in relatively straight lines and connecting that information with their prior knowledge to make inferences about the diabase filling in the existing cracks in the granite. Barbara claimed that granite was older and diabase was younger ("I think what happened is that the granite was here first and that was the oldest and the black came up through the cracks from the mantle."). Meanwhile, the instructor asked the two teachers to consider the alternative, granite being younger and diabase being older. In response, Barbara constructed evidence from her observations for her claim that granite was older and diabase was younger. She read out information about the two rocks exhibiting different visual patterns: the granite appeared to crack or fractures in straight lines and the diabase had a curvy or flowing appearance (see Figure 2). Barbara's prior knowledge may have directed her to pay attention to these visual patterns, which were then instantaneously read out and became an inference that the diabase flowed into the granite. This inference, for her, was evidence in support of the claim that diabase was younger than granite.

Barbara: It just seems like the black [diabase] flowed around because, when you look at the stripes going up, like, this one here. To look at that, it looks like that kind of filled in a crack that was already in the granite. As opposed to, if it was going another way I don't see the black splitting like that, as well, because it looks like it doesn't split like that as much. When you look at the rock [diabase] itself, it doesn't not have those clean sort of fractures that you see in, the granite seems to have those.

Instructor: So, I hear you telling me that you are seeing the black stuff seems to cut into the granite.

Barbara: Yeah, looks very different // Instructor: So // I feel like it filled into a fracture that was there in the granite, the granite fractures nicely like that. Where as, I don't know if this [black rock] does as much, I mean this seems to flow around, in it's pattern too, it seems like it flowed around things and fills in cracks that were already in the granite, its kind of flowing in.

Barbara read out that the "granite fractures nicely" and generated an inference about the motion of the diabase when it was a melt. The diabase "fills in cracks that were already in the granite" and "it just seems like the black [diabase] flowed around." Diabase is a solid rock, but her inference was about its historical motion. Additionally, she read out information that refuted an alternative inference that the diabase did not crack in a way that was similar to granite. "When you look at the rock [diabase] itself, it does not have those clean sort of fractures that you see in, the granite seems to have those." Using the patterns she read out from the rock, combined with her prior knowledge, Barbara produced evidence to support her claim that granite was older. The evidence also refuted the alternative inference, that the diabase was older. These claims were also supported by another inference and relevant readout about the light colored rock as granite and the black rock as different from granite. In addition to the claim about relative ages of diabase and granite, there was also a proximate claim about diabase having flowed in the past.

In summary, Barbara read out information about (1) the granite "cracking," and (2) the diabase having a particular pattern with none of the clean cracks of granite. Barbara generated an inference that the diabase flowed around the granite. This inference was taken to be evidence for the claim that the granite was older than the diabase. This case illustrates successful construction of evidence based on the information that was read out and connected to their prior knowledge and supported inferences about the diabase flowing, which in turn functioned as evidence for the claim that granite was older than diabase.

Case II: Incorporation of Multiple Pieces of Evidence into a Model

This is a case of a teacher successfully incorporating multiple pieces of evidence into a model. At the end of the morning of the first day, the teachers were asked to construct models of what was happening geologically at three points in time based on prior observations. Barbara mentioned information that she read out from the rocks and several inferences functioned as evidence for her claim about granite being older than diabase.

Barbara: It appeared that the granite was kind of fractured, very straight lines. And that the, diabase, if it was it diabase, I have to find out about that. It appeared that the black rock [diabase], was probably the middle age rock, warm and molten, like it must have flowed through the cracks and crevices. And went around things. Looking at it, in places where it was swirling, from places where it was being cooled. So we thought it was middle. And then the glacial erratics, which we didn't see any in that area, but the one I had seen on the other side, was definitely. And, I had said it was the youngest rock, but then Naomi brought up, well said it was may not have been the youngest but newest arrival, to this area. So, it was somewhere else and then just brought here. So I think that was...

Gina: You don't know what it was made of?

Barbara: It looked like granite, but different. I don't know if it was Lucerne Granite, but I don't know. It was all grey and white as opposed to the pink granite that we were seeing.

Geologist: What about the very bottom there? What did you all…?

Barbara: Glacial erratic were sitting on top of both rock layers. It was just seeing like it was dropped there. You know, it didn't look like anything else, and it was this rounded rock that didn't fit in with sharp edges of granite that we were seeing around it.

Barbara discussed her evidence for granite being older than diabase. She read out information about the straight-line fractures in the granite, which supported her inference that the molten black diabase flowed through the existing cracks and crevices in the granite while it cooled. This inference then became evidence for the diabase being middle aged (200 million years old) and the granite being older.

Then, Barbara switched to discussing glacial erratics. She mentioned having seen a glacial erratic, which suggests that she had read out the features of a particular rock and connected them with relevant prior knowledge in order to identify that rock as a glacial erratic. The glacial erratic was taken to be evidence of the youngest rocks; we do not know why, likely, she had prior knowledge of the recent glaciation period, which was discussed elsewhere in the workshop. Gina asked Barbara about the composition of the glacial erratic. Barbara mentioned that it looked like granite, which implies that she read out information from the rock and connected that to her prior knowledge to determine that the specific rock was granite, but she was unsure about whether or not it was a particular kind of granite, Lucerne Granite. This provisional identification was made from her having read out information about the color of the rock. It looked grey and white, instead of pink, which was the typical color of the surrounding rock. At the end, one of the geologists asked her about glacial erratics. She then generated an inference in which glacial erratics were sitting there, possibly dropped there. She may have read out information about how erratics looked different from surrounding rock; the surrounding granite had sharp edges while the erratic was rounded. Accordingly, Barbara constructed a series of claims, granite as the oldest rock, diabase as the middle aged rock, and glacial erratics as the newest arrival. In generating these claims she constructed evidence for why granite was older than diabase, it appeared that the molten diabase flowed into existing cracks in the granite, and why the glacial erratics, which were composed of ancient granite, were newer arrivals to the local area than the granite bedrock.

Case III: Problematic Evidence Construction due to Uncertainty about Chatter Marks

This is a case of problematic evidence construction as the teachers lacked sufficient knowledge to determine the nature of the markings they were observing. This case came from the second day of the workshop when Barbara and Naomi discussed marks in the bedrock that may or may not have been chatter marks. They made observations of glacial markings at Fraser Point in order to develop a second round of models for the three previously mentioned time periods. Based on their new observations, Barbara and Naomi were unsure of whether the specific marks they were "seeing" were chatter marks or not. Chatter marks are evidence of glaciation and have a characteristic quarter moon shape that is aligned with the direction of glacial travel. The two teachers discussed several alternatives, perhaps these marks were cracks, striations or scratches, and they discussed how they might know if these marks were chatter marks or not. This conversation occurred over six minutes, one small excerpt is presented below. Throughout the conversation the teachers wrestled with whether the different markings they were observing on the rock were chatter marks or not. The issue of chatter mark identification was not resolved. Therefore, this is a case of trying to construct evidence, but there was little success due to uncertainty in determining chatter marks.

Naomi and Barbara read out several markings in the bedrock and the information read out as combined with their prior knowledge influenced them when trying to decide what kind of markings they were. Naomi first read out information about a marking when she asked Barbara if the markings were striations ("I haven't seen actual striations in a long time, could this be?"). Barbara responded with a possible inference about chatter marks ("Looks like chatter marks, it could be thought, going in the right direction?") and included information about why these markings might be chatter marks: they are going in the right direction. Barbara drew on prior knowledge about direction being important and she read out both the marks and their direction. Naomi agreed with the directionality, but had a concern about what was causing the chatter mark ("Could be something else dragging it."). Then Barbara read out new information about the depth of the marking ("It could have been, doesn't look like it was that deep, you know.") At this point they had read out some markings that might be chatter marks, but had not made a solid inference about if these were or were not chatter marks. Then, the conversation switched to a different mark in the rock and Barbara again asked about the identification ("What did they say, about these here? These cracks? Did they say that they are striations?"). In response Naomi said, "I've seen striations before. I've had them pointed out to me by a geologist, and I didn't think. That looks more like a crack to me." Here she was explicit about her relevant knowledge, having had striations pointed out to her in the past, she was uncertain about whether these were striations. Barbara then agreed, and Naomi continued to explain why this one was not a chatter mark ("Cause this should be more like a scratch.") Again, the conversation switched to a different mark in the rock, and this time Barbara was more convinced of it being a chatter mark ("There is some down there. It seemed like it was better, looks like chatter marks.") Naomi and Barbara again read out information about directionality and decided that these were more likely to be chatter marks ("they chatter marks were going in that direction. Kind of like that. I bet that's what they are"). This conversation stretched on while they continued to observe and try to identify additional markings.

Both teachers accessed some prior knowledge about identifying chatter marks as connected to glacial directionality. They read out specific markings in the rock including details about depth and shape, which implied direction. These readouts were connected with relevant prior knowledge while they tried to generate an inference about whether or not specific markings were or were not chatter marks, and they also discussed alternatives. In a short time period they looked at several markings with varying degrees of confidence. The inferences were tentative because the teachers were unable to decide if the markings were or were not chatter marks and they were unable to make a clear argument for their uncertainty. This tentativeness might have been a manifestation of a lack sufficient prior knowledge. The lack of a solid inference that could have lead to evidence is important because chatter marks are generally evidence of glaciation, and thus they did not construct evidence for glaciation in these moments. Another factor is that the specific markings at this location were not ideal cases of chatter marks, and we would expect this to cause ambiguity for learners. This case illustrates that construction of evidence can become problematic when one either does not have sufficient prior knowledge or a certain kind of prior knowledge or when the readouts are ambiguous.

Case IV: Different Readouts of Whether or not Dikes Extend Below the Surface

Similar to Case III, this is a case of a challenge with constructing evidence, namely conflicting readouts leading to different claims. This case took place on Day 1 of the workshop when the teachers were in the field making observations of the bedrock, and they constructed three models, one for each time period. The instructor aimed for the teachers to see the dikes as cutting through the granite and running for a significant distance horizontally. In this instance, a small group of individuals discussed the question of whether the dikes extended below the surface or not. One possibility was that dikes seen on the surface extended below the surface in vertical columns. Another possibility was that dikes were inclusions, or chunks of rock, stuck in the middle of the granite and did not extend below the surface. Settling this question was important because two different conclusions could be reached based on one's interpretation of the evidence. If the dikes were viewed as cross-cutting the granite this would be used as evidence of dikes being younger than granite. On the other hand, if the dikes were viewed as inclusions in the granite, than the diabase would be older than the granite.

The teachers were asked to draw cross-sections to show the relationship between the rocks below the Earth's surface. Initially, teachers had trouble drawing what was below the surface. The instructor suggested the teachers should find a place where the rock was cut so they could see a cross-sectional view beneath their feet. The instructor directed the group to look below and asked if the dikes extended below the surface. ("You might have to look around a bit. But you might find a place where it was cut and you can look below. But, would you assume, like, coming over and looking at this. Would you assume that this is going to be really, really deep?") In response he heard both "yes" and "no," which prompted the next conversation about whether the dikes extended below the surface or not. Gina was not reading out information about the dikes going underneath ("You don't see if from down there, there isn't anything that comes out from underneath.") This supported the inference that the dikes did not extend below the surface. Lisa and Kelly both read out information about the dikes that supported a different inference: dikes extending below the surface. "Lisa: No, but it could go down there. It is going down there instead, so it's vertical. That doesn't mean that it doesn't stand up and (muffled argument). Kelly: Could be a big column." Then, Carol, similar to Gina, also read out the dikes as a chunk ("I think of it as a chunk of") and inferred that it did not extend below the surface.

This case is interesting because the teachers were likely all looking at the same rocks, but not reading out the same information. From different readouts we would expect them to draw different inferences, and construct different evidence. Lisa and Kelly generated an inference that the dikes continued below the surface, which could be taken as evidence for a claim about dikes being younger as they cut through the granite. Gina and Carol generated an inference that the dikes did not continue below the surface, which led to different inferences, evidence, and claims than Lisa and Kelly. Another possibility that cannot be ruled out is that they were drawing on different prior knowledge, however, given that the teachers appear to "see" different things from the same apparent rock, there is an indication of them having different readouts and not only different knowledge. Reading out the pertinent information is important in evidence construction, and this case suggests that one challenge in constructing evidence is what information one reads out of a situation.

Discussion and Conclusion

In this paper we used coordination class theory to show how learners constructed evidence in the field as their prior knowledge interacted with their observations. Cases one and two illustrated successful construction of evidence while cases three and four each illustrated a challenge with constructing evidence, including difficulties with background knowledge, and individuals having conflicting readouts. Coordination class theory was useful in describing these examples because it provided a way to conceptualize successful evidence construction and what can be problematic, both of which may impact how individuals learn. As we pointed out in our review of the literature, evidence construction is currently under-conceptualized. Thus, our work provides an early depiction of what evidence construction might look like in a field-based setting. Current research in geoscience education recognizes the importance of field experience. Studies on expertise have shown how experts construct evidence, but our work goes a step beyond this by beginning to elucidate how evidence is constructed in a field setting. We also see our work as generally applicable to the science education community. Evidence construction is a major part of many of the scientific practices highlighted in the recently released *NGSS*. Thus, understanding both the process and the difficulties learners might encounter in evidence construction should inform the development of heuristics that can support learners in successfully constructing evidence as they engage in the learning of science.

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Acknowledgements

This work has been supported by NSF Grant no. DUE-0962805.