How a 6th Grade Classroom Develops Epistemologies for Building Scientific Knowledge

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Abstract: Current reforms in science education emphasize scientific practices as the means by which students develop and use scientific ideas. However, supporting students in engaging meaningfully in scientific practices is challenging because we do not know much about what students learn *about* the process of engaging in scientific practices, or the epistemic criteria guiding their work. In this paper, I characterize how classroom communities develop sets of epistemic heuristics by engaging in scientific practices over time. Specifically, I present how one classroom community's implicit answers to "*What kind of answer are we working to build*?" and to *"How does the idea we are trying to build relate to other phenomena and ideas?"* shifted throughout a unit. I argue that these shifts were designed into the curriculum, but required strategic work on the teacher's part; and that these shifts reflect epistemic learning.

Keywords: scientific practices, knowledge building, epistemology, communities of practice

Introduction

Current reforms in science education emphasize scientific practices as the means by which students develop and use scientific ideas (NRC, 2012). These reforms draw upon a situated perspective of learning in which students learn through participating in a community of practice to make progress towards a shared goal (e.g., Brown & Campione, 1996). In science classrooms, this shared goal is to build scientific knowledge that is useful for explaining the natural world. Scientific practices, then, are the ways that students engage to build that knowledge.

Supporting students in engaging meaningfully in scientific practices is challenging because we do not know much about what students learn *about* the process of engaging in scientific practices. Careful research has begun to characterize what student engagement in specific practices looks like over time (e.g., Schwarz, et al., 2009). However, students can still engage in the "doings" of the practices without an understanding of how and why those practices are useful for building knowledge (i.e., by rote). In addition to "doing" the practices, students should come to understand the "hows and whys" undergirding those practices: both the practical heuristics for how to build knowledge (Berland et al., 2015), and why those epistemic heuristics are useful (Manz, 2014).

In this paper, I aim to characterize how a classroom community develops sets of epistemic heuristics (i.e., epistemologies for scientific knowledge building) by engaging in scientific practices over time. Specifically, I examine how middle school students' consideration and use of two specific epistemic heuristics changes over the course of one content-area unit, and how those changes are supported by the teacher and the curricular context. By providing empirical evidence for students' knowledge-building work in practice, this study contributes to our growing understanding of how to support students' meaningful engagement in scientific practices.

Developing situated epistemologies-in-practice for scientific knowledge building

From a situated perspective, learning involves shifting how one participates in a community of practice. The community is characterized by their "joint enterprise," or their collective set of goals that gives the community a sense of what they are all about (Lave & Wenger, 1991). Applying a situated view of learning to schooling means that students should be learning disciplinary content in a context in which their tasks are guided by and shaping their understanding of the "joint enterprise" of the discipline. In science classrooms, that joint enterprise is building explanatory understandings of the natural world (Louca et al., 2004). When working to explain those natural phenomena, students are engaged in practices that help them make progress towards building explanations. Their engagement in these practices and the knowledge they develop both is guided by and shapes their understanding of their community's joint enterprise, or what it means and what it takes to build scientific ideas.

In this paper, I focus on understanding what students learn about what it means to build scientific ideas in science learning contexts that are organized to engage students meaningfully in science practices. Because what they are learning is epistemic—related to the nature of scientific knowledge and the work of building that knowledge—I turn to theories of epistemology to further focus my investigation.

Often, the epistemologies relevant for scientific work are phrased as unitary statements, such as "scientific knowledge is tentative." However, knowing these declarative statements has little effect on the nature of students' work. Instead, "practical epistemologies," or smaller pieces of epistemic knowledge that are combinations of idea and action, guide the actual work that students do (Sandoval, 2005). These practical epistemologies consist of sets of “epistemological resources,” or “cognitive resources for understanding knowledge” (Louca et al., 2004, p.58) that are differentially activated depending on the context. For example, a student who thinks the goal of a task is to get the right answers on a worksheet may quickly scan through a book, looking for key terms. His activity is guided by notions that the ideas he is working to produce are already known and simply need to be stated. In contrast, the same student may carefully think through what is happening to make a cookie odor travel around a corner if he thinks the goal is to draw from what he knows about how matter behaves to work out an explanation. Thus, students always have an implicit answer to how they build science ideas, though their answer may not align with a disciplinary one. Learning how to build science ideas in disciplinarily authentic ways requires that students gradually, over time, engage in knowledge-building work that entails continual activation, or consideration, negotiation, and use, of the sets of epistemic criteria valued by disciplinary science.

The disciplinary answers for how to build scientific ideas take the form of *epistemic criteria*, or specific rules of thumb for how to construct and evaluate knowledge (Chinn, Buckland, & Samarapungavan, 2011). I focus on how students draw on resources for two criteria: the notion that scientific answers should provide mechanisms, and that they are working to build general models that explain multiple phenomena. Ideally, through engaging in work that entails continual activation of these criteria, students come to see how and why these disciplinary criteria are useful and productive for building scientific knowledge. This study aims to characterize this epistemic learning process, or how students’ use of various epistemic resources for these criteria changes over time.

To characterize students’ use of disciplinary criteria, I utilize Berland et al.’s (2015) Epistemologies-in-Practice framework. This framework identifies four epistemic criteria that are generative for both scientists’ and students’ knowledge-building, including the two that I focus on here: accounts should be *mechanistic* and accounts should be *generalizable* but built from *specific* phenomena and cases. The framework then broadens those criteria to the questions, or epistemic *considerations* (ECs) that those criteria—and many other non-disciplinary ones—serve as an answer to: *What kind of answer are we working to build?* and *How does the idea we are working to build relate to other scientific phenomena and ideas?* Thus, students tacitly consider and respond to these questions in making decisions throughout their knowledge-building process. Consequently, students’ implicit answers to these ECs, and therefore the epistemic resources guiding their work, are visible in classroom discourse and interaction organized around building scientific knowledge.

This study identifies and characterizes students’ epistemic work during their knowledge building activities over the course of one 6th-grade unit. My study focuses on a classroom with an expert teacher, Ms. L., who is using curriculum materials designed to engage students meaningfully in scientific practices (Krajcik, McNeill, & Reiser, 2008). I examine how Mrs. L’s classroom community develops epistemologies for building scientific knowledge by investigating the following research questions:

1. How do the classroom community’s consideration and use of two epistemic criteria for building scientific ideas shift over the course of one 12-week unit?
2. How are these shifts supported by (a) the curriculum design and (b) the teacher? In what ways do these shifts indicate epistemic learning?

Methods

To investigate these questions, I conducted an instrumental case study to develop and empirically articulate the construct of interest—epistemic considerations in practice—and to provide a rich description of how this classroom community develops knowledge-building practices and norms. The primary data source for the study is a collection of video recordings of selected classroom lessons from one unit during the January-April 2013.

The curriculum for the unit organizes students’ work around a driving question: *how can I smell things from a distance?* This question sets the specific “joint enterprise” for the unit, the overarching question that they are working to explain. I selected lessons from this unit where the (intended) design of the curriculum provided opportunities for explicit knowledge-building work around the main scientific principles that the class was working to develop (e.g., lessons in which students were drawing and presenting models, or “jigsawing” interpretations from evidence to explain a phenomenon). In total, I selected 7 class periods, or approximately one every two weeks of the unit. The unrecorded class periods involved activities such as conducting investigations and interpreting data to answer sub-questions; reviewing readings; and taking quizzes or tests.

In order to see how the classroom community’s consideration and use of epistemic criteria changed over the course of the unit, I selected epistemically rich episodes, or moments in which the classroom discourse provided evidence of the students’ and teacher’s implicit answers to *what kind of knowledge they were working to provide* and *how the idea they were working to understand related to other scientific phenomena and ideas.* To select these episodes, I and a team of researchers content-logged the video according to activity types based loosely on the 8 scientific practices described in NGSS (e.g., “Developing and Using Models”; “Designing and Carrying out Investigations”) as well as codes for general classroom activities such as “Free Time/Logistics.” We then "tagged" the video for any potential evidence of epistemic considerations (ECs) in student and teacher discourse. For example, when "tagging" for evidence of someone considering how the idea they were working to build related to other scientific phenomena and ideas, a coder marked any time a student or the teacher brought in another example (e.g., "It's like Jello") or used a generalization (e.g., "Well, there's always dust in the air"). After content-logging and tagging, the research team used the distribution of tags as "sensitizing indicators" to select episodes for more in-depth analysis. We selected chunks of time that included a cluster of several EC tags within a single segment of activity. Episodes averaged 2:28 in length. The research team transcribed each episode by turn of talk. I then coded each turn for the two ECs of interest, Nature and Generality, as described next.

To characterize *Nature,* or the classroom community's answer to *"What kind of answer are we working to provide?",* I first coded each turn of talk within each episode for the elements of explanatory and other types of accounts. Elements of an explanatory account included describing the phenomenon, identifying factors (such as air particles) and unpacking factors (such as playing out the behavior of the air particles). Elements of other types of accounts included providing known-answer information, giving an illustrative example, describing details from personal experiences or a class activity, and imagining a hypothetical scenario. I then categorized each episode based on whether the majority of talk turns contained *explanatory* or *other* elements. If the majority of turns of talk contained explanatory elements, I characterized the episode as building an *explanatory account.* If the majority of turns contained other elements, I characterized the episode as building an *other type of account*.

To characterize *Generality,* or the classroom community's answer to *"How does the idea we are trying to understand relate to other phenomena and ideas?",* I first coded each turn of talk for whether the speaker was talking about a specific phenomenon, such as litmus paper changing colors; a general idea or generalization, such as the fact that all matter can exist in three states; or a representation, such as a model, that abstracted from the specific case somewhat. I then coded whether the discussion made connections between specific, represented, or general ideas, or if it simply focused on characterizing one type. If there were connections made, I coded the nature of the connections as either a connection between ideas that were both *known,* such as using a specific example like ice melting into water to illustrate the general principle about matter existing in three states; or a connection between ideas where one of the ideas was unknown and *built* during the course of the episode. For example, students drawing models to explain how and why balloons shrink in liquid nitrogen are *building* their explanation for that phenomenon.

In addition to coding for evidence of each of the ECs in discourse, I coded for teacher prompts for consideration in one of these epistemic areas. For example, a teacher could prompt for a particular type of account (coded as a prompt for Nature) by saying, "But why? Why can some people smell better than others?"

Findings and Discussion

From the analysis of the selected knowledge-building episodes from one unit, I present how the classroom community's answers to the two ECs of focus (Nature and Generality) shifted over the course of the unit. Taken together, these shifts demonstrate how the classroom community's answer to the question, "How do we build ideas?" changed over the course of one unit. The shifts are: 1. Classroom talk increasingly contained elements of explanatory accounts and they increasingly constructed coherent explanatory accounts as the unit progressed; and 2. Almost all episodes contained connections between general and specific ideas. Early in the unit, those connections were between known ideas. As the unit progressed, students increasingly built ideas, primarily by making and comparing representations (models) and articulating general principles from those representations. I present each change in more detail and interpret them in the context of the curricular and teacher supports.

Design of the curriculum and distribution of epistemically-rich episodes

The unit of focus for this study was organized around the driving question, *How can I smell things from a distance?* Through cycles of observing phenomena, generating questions, developing initial models or explanations, conducting investigations, revising those models or explanations, and generating additional questions, students build explanations to three sub-questions that together answer the driving question. These questions, and the principles that students develop over the course of several lessons to answer them, are:

1. How does an odor get from the source to my nose? (Lessons 1-5). *Principles: Substances are made of particles; in gases there is empty space between the particles; particles are moving constantly.*
2. What makes one odor different from another? (Lessons 6-9) *Principles: Every substance has unique properties; varying molecular arrangements of atoms give substances their properties, including odor.*
3. How can a material change so you can smell it? (Lessons 10-16). *Principles: The particle model explains states and phases of matter in terms of particle distance, movement, speed, and arrangement.*

The lessons that I selected for observations were ones where students explicitly worked to build one of these principles. Though all of the activities in the unit were designed to help students work towards these ideas, there were various points at which they used an activity to begin pulling some of those pieces together. Table 1 represents the duration of various activity types present during each lesson and indicates the number of epistemically-rich episodes during each activity type (including time that was coded for multiple activity types). Note that a variety of activity types occurred throughout the observed lessons, but the activities during which most of the epistemically-rich episodes occurred varied and was not necessarily proportional to the amount of time spent on that activity.

Table 1. Distribution of activities during each class period.

Activity Types	**L1**		**L3**		**L4**		**L6**		**L11**		**L12**	
	Min	Ep	Min	Ep	Min	Ep	Min	Ep	Min	Ep	Min	Ep
Asking questions, making predictions	0:00		11:16	3	6:04	1	3:00	2	1:18	1	2:12	
Constructing explanations	8:06		0:00		15:07	7	14:42	5	12:01		8:40	5
Doing an experiment	7:36		0:00		4:50	2	9:00	1	3:26		0:00	
Discussing an experiment	4:36		0:00		16:08	4	18:00	3	11:33		3:01	
Discussing a phenomenon	7:06	2	11:15	4	1:55		0:00		0:53		7:00	
Drawing or presenting models	8:47		7:44	2	13:14		14:00	2	17:13		19:18	6
Logistics or independent work	*16:10*		*14:29*		*2:48*		*1:00*		*11:40*		*13:14*	
Total*	**39:59**	**2**	**40:06**	**9**	**41:24**	**7**	**37:01**	**5**	**39:55**	**1**	**39:46**	**6**

*Sum of activities and episodes may be more than the represented total due to double-coding of activity types.

Nature: Shifts in "What kind of answer are we working to provide?" over time

Of the 30 epistemically-rich episodes, only six were characterized as episodes where the classroom community was providing other types of accounts. These six episodes occurred during the first three observed lessons, as illustrated in Figure 2a. During these six episodes providing Other accounts, students were primarily recalling details from their personal experiences and providing known-answer information, as shown in Figure 2b.

(a) (b)

Figure 2. "Nature" characterization of episodes by lesson (a) and of student talk by episode type (b).

During the other 24 episodes, the classroom community was working to provide explanatory accounts. Student turns of talk contained all three elements of explanatory accounts, though they most often identified factors. Importantly, the turns of talk containing explanatory elements were not isolated student turns in response to a teacher question (e.g., T: What is air made of? S: Air particles). Instead, multiple turns of subsequent student talk worked to explain a phenomenon, often by weaving together both explanatory elements and elements of other account types. For example, in Lesson 3, Ms. L asked if all substances needed to be cold to "freeze." Students responded, "No," and then Ms. L asked them to recall the example from last night's reading about candle wax. Stefanie responded by *describing her personal experience* with candle wax: "Once stuck my finger in some melted wax…I just waited for a bit, and then it started to dry up and turn hard." After describing that experience, Noelle *described a similar phenomenon*: wax hardening after you blow out birthday candles. Megan and Peter then *identified two important factors* within the description of that phenomenon: "[The wax] hardens pretty quickly," "Especially when it touches the cake." Although not what Ms. L had hoped to identify (that temperature change rather than absolute temperature mattered), they identified two factors relevant to room-temperature "freezing": time, and contact with another substance (in this case, cake).

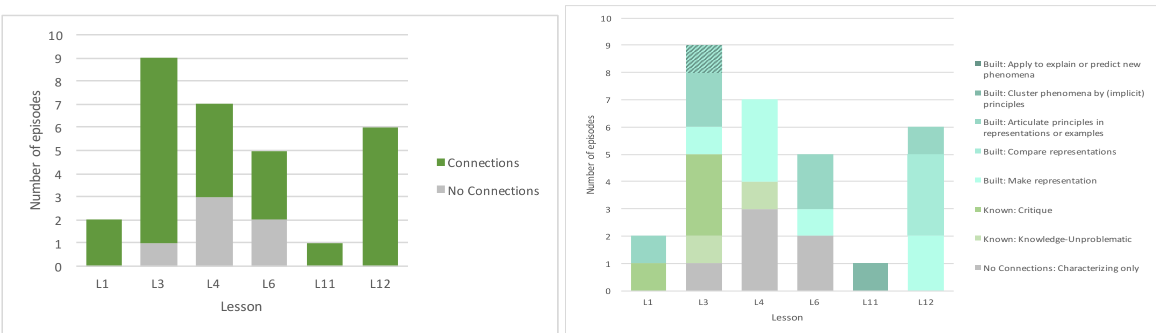
However, neither the number of turns of talk containing explanatory elements nor the types of explanatory elements they contained shifted much over the course of the unit. Students began describing phenomena, identifying factors, and unpacking those factors in Lesson 3 and they continued to do so in similar proportions through Lesson 12. Instead, what shifted were the number of elements within each individual turn of talk. In Lessons 1-6, each turn of student talk contained an average of between 1.1 and 1.2 elements. In the episode about the candle wax above, Stefanie, Noelle, Megan, and Peter's turns would each be coded for one element. In contrast, the turns of student talk in Lessons 11 and 12 contained on average 2 and 1.5 elements, respectively. In other words, students provided more complex pieces of an account within a single turn of talk later in the unit.

To illustrate this difference, compare the individual turns in the episode about wax hardening to this exchange about squirrels finding nuts. After spending almost an entire class period tinkering with a computer model that visualized particle motion and temperature, Niral spontaneously identified *another phenomenon* for which temperature is a *relevant factor*: "Isn't one of the reasons why squirrels look for their nuts before winter is because when the ground freezes it's harder to smell nuts?" Katerina agreed with him, *unpacking and coordinating* the implications of that factor on particle motion: "Because when the nuts freeze, the molecules, you can't smell them as easily […] because when it's warmer the molecules speed up and then it has more energy and can get to [the squirrel] faster, but in winter it can't." Each student provided multiple elements of the explanatory account.

Over the course of this unit, the types of accounts that the classroom community built during during epistemically-rich episodes shifted to become entirely explanatory. In addition, students gradually began incorporating multiple explanatory elements (e.g., identifying factors and unpacking them) in a single turn of talk. Taken together, these shifts suggest that the classroom community's answer to "*What kind of answer are we working to provide*?" shifted from "definitions and facts" to "coherent mechanistic explanations of phenomena" that became more complex over time.

Generality: Shifts in "How does the idea we are trying to understand relate to other phenomena and ideas?" over time

In addition to identifying the type of account that the classroom community was working to build, I characterized how they were going about building that account with respect to the connections between general and specific ideas they were using to do so. As shown in Figure 3a, most episodes contained connections between general, represented, and/or specific ideas. In the six episodes that did not contain connections (in L3, L4, and L6), the class was characterizing a specific phenomenon while doing or discussing an experiment.



(a) (b)

Figure 3. Number of episodes with connections (a) and connection accomplishments (b).

The nature of the connections that the classroom community made between general and specific ideas shifted over the course of the unit, as shown in Figure 3b. In about half of the episodes during the first three lessons, the classroom community made *known* connections, such as using specific examples to illustrate general principles. Interestingly, however, four of the six known-connection episodes treated the connection as a *critique* of either the example of the general principle. For example, during Lesson 3 while reviewing an idea from their reading, a student stated the principle that "All matter can exist as a liquid, a solid, and a gas." Rather than accepting the principle as a correct and indisputable answer, though, Ms. L intentionally challenged it: "That is crazy to think about. So all matter can exist as a solid and a liquid and a gas. So I'm thinking of like, what would be hard to think about, like maybe rocks. A rock is a solid. I can't—can I get that [points to the word "liquid"]?" In the discussion that followed, students brought in classes of examples that show that rock can melt: cement has a liquid form, and lava is melted rock. They decided that a rock could become liquid, and possibly even gas, with enough heat.

These critiques of known-answer information often led to episodes where the class built or modified a general principle from their examples. Immediately following the rock discussion, Patrick asked about a pencil: "How can a pencil be gas?" The class talked through what would happen when you add heat to a pencil, and they decided it would probably start on fire before it would melt. They concluded by modifying their principle about the states of matter to say that maybe some things can go straight from a solid to a gas! Although burning is technically a chemical reaction and not a phase change, Ms. L's framing of the principle as something that they could question opened the discussion for counterexamples. When a student provided one (pencils), their work through what would happen when heating it up led them to construct a sub-principle or boundary condition.

Towards the end of the unit, the majority of the episodes involved students building ideas: creating representations, comparing those representations, and articulating general principles from them. The discussion of students' models for how a balloon shrank and grew back in different temperatures in Lesson 12 illustrates these patterns. After discussing the specific mechanisms portrayed in several individual balloon models, Ms. L asked the class, "What are we agreeing on? I mean like, what is it that we agree on?" Though there are several ways one could interpret this question, Ramona interpreted it as a call for generalizing across the models:

Ramona:	Um. That, uh, when the balloon gets smaller, like, it's usually because that the molecules and particles are like, kind of compact, they're compacted together.
Ms. L:	Mm-hmm.
Ramona:	It kind of like, allows its space to like, like, kind of like, let loose in the balloon, and when it gets warmer, it kind of like, lets molecules kind of like split out.

Although she is using the context of the balloon, she gives several indications that she is talking about balloons shrinking in general: she uses the term *usually,* and she then speaks about what happens in present tense, indicating what happens in general rather than what happened during the specific instance they were modeling. Ramona identified the general idea that all the students (based on their models displayed on the board) seem to be in agreement that the cold balloon gets smaller because the air molecules are "compacted together," unlike when molecules are warm and allow the empty space to "let loose" and the molecules to spread apart. This general pattern was built from their collective explorations of a specific phenomenon.

Overall, the shift to exclusively *building* connections between general and specific ideas by the end of the unit suggests that the classroom community's answer to *"How does the idea we are trying to understand relate to other phenomena and ideas?"* shifted as well. From the beginning the classroom community demonstrated that the ideas they were trying to understand needed to make sense with other ideas and experiences. However, the nature of those connections between ideas and experiences shifted from, "We connect phenomena and principles to critique known information" to "We connect phenomena and representations to build general principles."

How did features of the learning environment support these shifts?

In many ways, the curriculum was designed to support students in doing what they did: constructing general mechanistic accounts that were built from exploring and modeling several specific phenomena. This is encouraging, both that students are learning the content *and* that they are finding that content useful for building explanatory accounts. And undoubtedly, learning the content supported them in expressing complex mechanisms and articulating general principles from those mechanisms. Other curricular features also supported these shifts. First, the familiarity of the initial phenomenon—smelling something that was cooking before you could even see it—and the accessibility of phenomena used throughout the curriculum supported students' identification of mechanistic elements. For example, by bringing in familiar examples such as wax hardening, students identified temperature and time as factors relevant to phase changes during Lesson 3, even though this "content" was not brought in explicitly until Lesson 10. These accessible contexts, along with Ms. L's affirmation of students' use of their experiences as both examples and counterexamples, made students' everyday ideas productive resources for providing mechanistic accounts, making critical connections (such as questioning whether pencils melt), and applying principles to novel phenomena (such as squirrels smelling nuts). Importantly, students drew on everyday ideas throughout the unit, suggesting they were an integral part of their knowledge building practice.

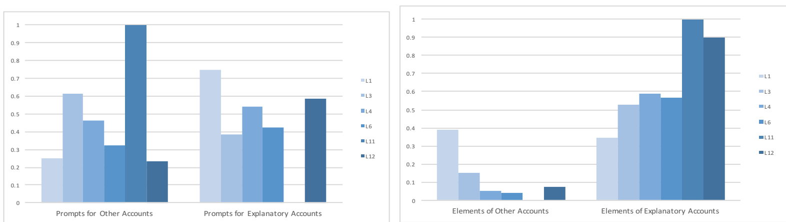
In addition, the use of diagrammatic models supported students' construction of mechanistic accounts, especially unpacking factors, as well as deep thinking about the specifics of a given phenomenon. By repeatedly drawing models for similar types of phenomenon (e.g., odor moving across a room; air compressed in a syringe; air in a balloon as it warms up and cools down), students' models highlighted what was general across those phenomena and they began using these general ideas (e.g., how molecules "usually" behave rather than how the specific air molecules in the cold balloon were behaving) to build explanations.

Finally, Ms. L worked very hard to gently problematize the kinds of ideas that she did *not* want them to be working to build. Early on, when students provided generalizations as known-answer accounts, such as, "Some people can smell better than others," or "All matter exists as a solid, a liquid, and a gas," she would affirm those answers, but was not satisfied with them. She would problematize a claim by calling into question the mechanism-- "Oh, interesting! So say more, How does that work?"—or by calling into question the reaches of its generality: "Excellent. That is crazy to think about. So I'm thinking like, what would be hard to think about. Like maybe rocks." These affirmative problematizations, highlighting the "interestingness" and "craziness" of science ideas, gently led students away from known-answer accounts and stand-alone generalizations and towards constructing mechanistic accounts built across multiple phenomena.

How do we know this is learning (and not just a response to framing)?

These shifts are interesting, and appear supported by the context. However, the sets of epistemic ideas that students implicitly choose to apply when approaching a task depend on context and shift in response to teacher framing. So what counts as epistemic *learning* rather than a response to framing? One form of evidence of learning would involve seeing students respond to the same types of teacher prompts in different ways over time. That is, if a teacher is consistently prompting for mechanistic accounts throughout the unit and students eventually come to respond to those prompts with mechanistic accounts, they have learned something about what kind of answer they are working to build. Or, more convincingly, if a teacher is consistently prompting for *other* types of accounts (definitions, known-answer facts, stories, etc.) but over time students respond to those prompts with mechanistic accounts, they have learned something about the kind of answer they are trying to build.

Ms. L's prompts for account type remained relatively consistent over the course of the unit, as shown in Figure 4. Her prompts for other types of accounts did decrease (with the exception of L11), though she was still prompting for other types of accounts more frequently than students were providing other types of accounts. In addition, about 50% of her utterances were prompts for mechanistic accounts *throughout the unit*, while the proportion of students' utterances that provided mechanistic accounts steadily increased until they were providing mechanistic accounts in almost every utterance. This suggests that not only did students learn that they were trying to build mechanistic accounts, they found those types of accounts to be useful enough to continue providing them even when the teacher was prompting for other types of accounts.



(a) (b)

Figure 4. Proportion of teacher prompts for types of accounts (a) and proportions of student turns of talk containing evidence of account type (b) over the course of the unit.

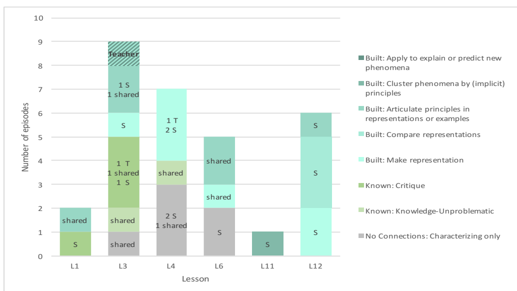


Figure 5. Distribution of generality work within each episode.

For evidence of learning about Generality, I noted who was doing the bulk of the work that led to the characterization of the episode. For example, did students begin using representations or general ideas after the teacher prompts them or does so herself? Or did they spontaneously do so, without teacher prompts or modeling? As shown in Figure 5, the bulk of the work was shared between the teacher and the students during episodes in the early lessons. In these shared episodes, the teacher's influence tended to be towards the beginning of the episode: she would prompt for or model a connection between ideas, such as whether one can melt rock. Students then made substantive comments for the duration of the episode. In these early lessons, Ms. L was framing the type of generality work she wanted her students to do. In contrast, by Lessons 11 and 12, the students drove the episodes: they independently represented and compared ideas and spontaneously articulated principles and related phenomena. This suggests that students learned that they were trying to build general ideas from understanding specific phenomena, and that they found building ideas to be useful enough that they did it independently.

Conclusions and Implications

I presented how, over the course of a 12-week unit, the classroom community's answer to "*What kind of answer are we working to provide*?" shifted from "definitions and facts" to "coherent mechanistic explanations of phenomena" that became more complex over time. In addition, students' answer to *"How does the idea we are trying to understand relate to other phenomena and ideas?"* shifted from "We connect phenomena and principles to critique known information" to "We connect phenomena and representations to build general principles." These shifts were designed into the curriculum, but required strategic work on the teacher's part; and these shifts reflect epistemic learning rather than in-the-moment responses to a specific framing.

This epistemic learning is key for students' deep understanding of what scientific knowledge *is*, what it can *do*, and how it came to be. Here, students learned to draw more consistently upon sets of epistemic resources that undergirded their engagement in knowledge building activities, which were often driven by the students themselves. Namely, this study provides empirical support for how students implicitly came to understand heuristics for how to go about building knowledge. In doing so, this study expands upon the Berland et al. (2015) framework by characterizing the range of the classroom community's answers to the Nature and Generalization considerations in greater detail; by demonstrating how, and at what grain size, a classroom community's answers shift; and by connecting the shifts in their answers to those considerations to specific features of the learning environment. This characterization of the development of a classroom community's epistemologies for science is a critical step in supporting teachers in engaging students in meaningful versions of scientific practices that engage students in authentic ways of knowing and doing science as members of a knowledge-building community.

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