MAKING MEANING: SHIFTS IN MEANINGFULNESS ACROSS THREE MODELING UNITS

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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ABSTRACT

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Recent reform calls for a more comprehensive approach to science education that positions learners as constructors of knowledge via scientific practices (NRC, 2012; Osborne, 2014). This ‘practice turn’ shifts from passive science learning to incorporating science actions with epistemic thinking (Duschl & Grandy, 2013; Ford & Forman, 2006; Osborne, 2014; Shouse, Schweinruber, & Duschl, 2007). Teachers are often underprepared in understanding the nuances of scientific practices, and frequently struggle with supporting students in meaningful practice engagement (Abd-El-Khalick & Akerson, 2004; Crawford, 1999; Davis, Petish, & Smithey, 2006; Duschl & Gitomer, 1997). Here, I draw upon the Berland et al. Epistemologies in Practice framework to define meaningfulness as being both authentic to the discipline of science and relevant to students: not only are students attending to epistemic thinking as they engage in a practice, but they are also buying into the need to do things that way (2016).

In this dissertation, I examine a classroom community (Mrs. L and her students) across three eighth grade modeling units to answer the research question How does a teacher support students in a modeling curriculum? Specifically, I want to know how Mrs. L and the students co-construct meaning around a practice in the classroom and then how students apply that meaning to their final models.

Based on the data collected in each of the units, I argue that meaningfulness co-constructed around a practice in a classroom setting can take
a variety of forms that maintain authenticity to the discipline of science and relevance to students. Furthermore, I argue that this meaningfulness can be abandoned as students construct their final models when the activity is approached as a product rather than as a scientific practice. Together, the findings from this multiple case study inform a larger body of research examining more effective supports for meaningful modeling and more productive approaches to modeling in the classroom and beyond.
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Chapter 1: Establishing a need to study meaningfulness

Despite the vast changes to the landscape of scientific discoveries in recent decades, as a whole, much of the paradigm of the discipline has remained constant: unanswered questions drive the need for scientific inquiry. Central to the discipline of science is the need to explain puzzling phenomena through making sense of data, but in what ways is education supporting the development of these skills in future scientists? Or, perhaps more importantly, how is education preparing the lay citizen for understanding and responding to a global science discourse? A large body of research suggests that the education styles commonly used in the past, such as memorization of science vocabulary and ineffective use of experiments, fail to produce students that are scientifically literate (Abd-El-Khalick et al., 2004; Chinn & Malhotra, 2002; Driver et al., 1996; Osborne, 2014; Schwab, 1962). In a shift from the passive, lecture-based science teaching, education reform has pushed for science learning to more closely resemble the things scientists are doing in the lab. That said, research suggests a turn toward scientific practices to reflect the predominant paradigm that school science should look less like “school” and more like authentic science (Ford & Forman, 2006; Osborne, 2014; Shouse, Schweingruber, & Duschl, 2007). By shifting student engagement in the classroom from procedural
activities to scientific practices, it allows students to do and think about science in a way that is meaningful to themselves and to the discipline of science.

The turn to scientific practices represents a shift from *doing* to integrating *doing* and *thinking* as scientists (NRC, 2012; Osborne, 2014). These practices not only engage students in constructing an argument from data they collected and analyzed, but also situate them in thinking about *why* they are engaged in these actions and *how* the decisions they make reflect the discipline of science. Scientific practices are unique from the traditional methods of science education because of this attention to students’ epistemologies, or their ideas about the nature of scientific knowledge (Duschl & Grandy, 2013; NRC, 2012). Previously, science had a rote connotation in which knowledge was transmitted from teacher to student and *knowing* was a result of textbook perusal or lecture. The turn to scientific practices affords students the opportunity to think about the nature of scientific knowledge more authentically through the construction of scientific knowledge.

As we support students in building science knowledge in a more authentic way, we must be aware of their current epistemologies, recognizing that for a vast majority of learners, the nature of scientific knowledge is still very much authoritative. Previous inquiry efforts decontextualized student ideas about the nature of science by separating these ideas from the doing of science; however, through meaningful experiences in the scientific practices, we expect students to become more sophisticated in how they view the nature of knowing science (Duschl, 2007; Sandoval, 2004). I am particularly interested in students’
epistemologies as they engage in the scientific practices, and how the decisions they make during knowledge construction indicate their understanding of science metaknowledge. For example, as students construct an argument to support their claims, they must decide who is the audience of their argument and what sort of evidence is necessary to convince that audience. We refer to these decisions within the practices as epistemic considerations (ECs) and argue that sophisticated attendance to these considerations and engagement in meaningful science learning are closely integrated (Berland, Schwarz, Krist, Kenyon, Lo, & Reiser, 2016).

Engagement in more authentic science is difficult for many teachers to navigate, and thus can be challenging to enact in the classroom (Abd-El-Khalick & Akerson, 2004; Crawford, 1999; Davis, Petish, & Smithey, 2006; Duschl & Gitomer, 1997). Although preservice training introduces teachers to scientific practices and might offer practical suggestions for implementation, this exposure is limited and lacks long-term support (Akerson, Morrison, & McDuffie, 2006; Van Driel, Beijaard, & Verloop, 2001). Furthermore, enacting meaningful classroom engagement within the practices can prove to be very difficult for teachers who are unfamiliar with the epistemic thinking that accompanies experience within the discipline of science (Abd-El-Khalick & Akerson, 2004), which then impedes teachers in appropriately scaffolding students in attending to epistemologies in the practice. Together, the challenges seen by teachers in implementing scientific practices can impact the extent to which students are able to experience the epistemic nature of the practices in a way that is sophisticated
and authentic to the discipline of science. In order to equip students for complex reasoning about the natural world, teachers must be prepared to support students in constructing meaning as they encounter scientific practices.

Many teachers are unaware of the few available recommendations for how to purposefully implement scientific practices in the classroom. This paucity of relevant teacher supports leaves many teachers to rely on their own conceptions of the practice and rarely results in meaningful science learning (Crawford, 2007; Davis & Krajcik, 2005; Luehmann, 2006). My goal in this study is to understand the ways in which one experienced teacher approaches the practice of modeling with her students, with the expectation that the findings can inform future teacher supports for engagement in practices.

**Purpose of Study**

In this study, I aim to further examine the ways in which a teacher scaffolds modeling in the classroom and then how those scaffolds have impacted the ways in which the students have constructed their final model. I want to understand more about the challenges facing a relatively experienced cohort of one teacher and her students as they navigate their roles and epistemologies in the practice, and ultimately use this knowledge to inform teacher educative materials in the future. As students engage in a practice, they are making epistemological decisions that guide the construction of a knowledge product (Berland et al., 2016). I expect that if students are effectively supported as they co-construct meaning in the classroom discourse, the epistemological decisions they make in the final model will reflect a more complex representation of that co-
constructed meaning. The teacher plays an integral role in these decisions by scaffolding the sensemaking and attending to the epistemologies in the practice implicitly through instruction, thereby framing the construction of meaning. By teacher framing, I refer to the ways in which the teacher experiences the lesson and how the teacher then communicates this information to the students through verbal and nonverbal cues (Bateson, 1972; Berland & Hammer, 2011; Goffman, 1974).

Together, these factors coalesce to result in co-constructed meaning in the practice, which can take on a variety of forms. Engagement in the practice that is meaningful to the classroom in terms of making science accessible may result in more student buy-in, but fail to exhibit sophisticated attendance to the epistemic considerations. This might manifest in activities that are entertaining to students, such as an artistic rendering of parts of a cell, but bear no higher cognitive purpose. Alternatively, engagement that is meaningful to the discipline of science might result in more content-driven attendance, but not student buy-in, such as worksheets that remove creative sensemaking from the students.

Ideally, a hallmark of effective enactment of the practices and co-constructed meaning is engagement that is authentic to the discipline and maintains student buy-in. My aim in these research questions is to better understand the kinds of meaning that students and teachers construct together. In this dissertation, I explore how the patterns of meaning co-constructed in a classroom and the meaning applied by students in their final models can be used to support authentic knowledge construction across an entire unit.
Research Questions

1. How does the teacher support students in a modeling curriculum?
   a. How does the teacher engage with students in the classroom to co-construct meaning?
   b. How do students apply the co-constructed meaning to the knowledge product?

For this research question, I will compare the ways in which a teacher engages with the students in the classroom discourse during three modeling units and how this engagement influences students as they build and reflect upon their final models. There are many shifts in epistemic thinking that can occur across units and time as teachers become more familiar with the goals of scientific practices and how to leverage student engagement in them; I am interested in the ways in which a teacher and group of students experienced in modeling construct and use meaning across a unit. In the three units within this study, the practice of modeling is prioritized either by curriculum design or by teacher re-design. Furthermore, the teacher and the students in our study are also participants in a larger longitudinal study examining engagement in practices over three years. I chose to coincide our research goals and data collection with the third year of the larger study, as I want to understand how an experienced teacher engages with students who are already familiar with scientific practices. Altogether, the modeling focus of the units and the acclimatization of the participants to scientific practices provides a unique context by which I aim to
analyze the variety of ways in which an experienced teacher can support students in engagement in scientific modeling.

In RQa, I aim to understand how the teacher and the students work together to construct meaning in the classroom discourse as they answer a driving question grounded in a phenomenon. I want to know more about the nature of the classroom culture: about the agentive nature of students as they introduce and respond to new ideas, and about the extent to which the teacher negotiates the roles of this epistemic agency. I also will analyze discourse to better understand how the students and teacher are attending to the epistemic considerations as they engage in a practice. Together, these patterns of agency and epistemic attendance will obviate the larger pattern of prioritization in the classroom. By this, I mean the kinds of ideas, goals, and considerations that take precedence in the classroom talk. This information will show how the students and the teacher work together to construct meaning, whether it is personal, scientific, or authentic meaning, in the classroom.

In RQb, I aim to understand how the students apply this meaning to their final constructed model in each unit. In this research question, I am interested in the patterns of students’ attendance to the epistemic considerations as they discuss their models. I want to know if the patterns of epistemological thought students put into their models match the patterns of epistemic considerations prioritized in the classroom discourse, and if not, in what ways they differ.
Together, these two research questions will help to answer a larger question about how best to support sustained meaningful engagement in practices throughout a unit. Because a classroom is a complex environment with participants who have a variety of goals, it is not unexpected that students might prioritize different epistemic considerations than those prioritized in classroom discourse, or even fail to apply the co-constructed meaning in their knowledge products. My aim is not to understand why these events happen, but rather to understand the patterns in the kind of meaning constructed by the students and the teacher and the ways in which students adopt or push against that co-constructed meaning as they build their final models.

**Expected contribution of the data**

The results of this study will contribute to our understanding of the current landscape of scientific practices in the classroom. Science education research is a growing field, and because scientific practices are highlighted in the national standards but not well-supported in teacher training, the research presented here will contribute greatly. Furthermore, the development of more refined meaningfulness codes will support our understanding of the interactions between the teacher and students and how those interactions support meaningful engagement in the practice. I expect that in the different cases we will see various ways in which the students and teacher construct and apply meaning to the final knowledge products, and overall, different ways in which a teacher can support her students in engagement in the practices. A multiple case study
methodology will furthermore add to the transferability of the results and thus provide access to future research for practitioners and education researchers.

RQa. How does the teacher engage with students in the classroom to co-construct meaning? A number of studies have shown that in general, teachers lack a full understanding of the practice of scientific modeling (Crawford, 1999; Crawford & Cullen, 2004; Danusso, Testa, & Vicentini, 2010; Davis, Petish, & Smithey, 2006; Justi & Gilbert, 2003; Windschitl & Thompson, 2006; Van Driel & Verloop, 1999). While many of these studies look at understanding what teachers know about modeling or how they apply the practice of modeling to their classrooms, few examined how the teacher attends to epistemic considerations with the students and how she negotiates the roles within the classroom (Eick & Reed, 2002). The research presented here further refines the Berland et al. framework to look at how the teacher implicitly and explicitly guides modeling and meaningfulness in the classroom and will therefore be useful in understanding how to better support teachers engaging in modeling (2016). Furthermore, the idea of examining three cases of modeling units taught by one teacher can offer valuable information about the ideas that an individual can possess about modeling and how his or her attendance to the epistemic considerations changes with those ideas. The information from this study will be useful in identifying ideas about modeling and providing scaffolding for teachers with conflicting ideas to engage in science with students in more meaningful ways.

RQb. How do students apply the co-constructed meaning to the knowledge product? Engaging in modeling does not necessarily mean that the
students will have a rich experience in the practice (Schwarz, 2009). Students rely on cues from teachers as they navigate the learning experience within the boundaries of the classroom culture (Berland & Hammer, 2012), yet the turn to practices aims to shift this reliance from the authority to the peers. Currently underrepresented in the literature is how construction of meaning via attendance to epistemic considerations and negotiation of roles can influence students in the ways they construct and think about their knowledge products. As I examine how this teacher supports and guides the construction of meaning in each unit, I am also curious as to how the students will either adopt or push against these moves. The information provided by this study will help to address what students find important and useful across time and can inform future work in supporting teachers and students in modeling practices.

**Theoretical Framework: Epistemologies in Practice**

In order to support students in developing a clear understanding of the discipline of science and the nature of scientific knowledge, scientific practices and reflection must be integrated in a meaningful way. As defined by the National Research Council, scientific proficiency is achieved when students can construct and use scientific explanations, generate and evaluate scientific evidence, understand the nature of scientific knowledge, and participate productively in scientific practices and discourse (NRC, 1996). To facilitate student proficiency in learning science, the NRC framework describes scientific practices as a means to emphasize both science knowledge and skill (NRC, 2012; NRC, 1996). This approach unifies the actions of science, such as designing an investigation,
with the epistemology of science, the *why, how, and to what end*. Moreover, it encourages students to question and critique, and these elements were lacking in prior approaches. Inclusion of these components further situates students in complex scientific reasoning (Berland & Reiser, 2008; Ford, 2008).

**Modeling in the classroom.** The traditional role of models in a classroom has been to display smaller features of a whole entity, focusing on the structures, names, and placement of these features. Modeling from the standpoint of the Next Generation Science Standards represents a shift in thinking about names to thinking about processes (NRC, 2012). Considered an explicit part of learning and doing science, scientific models are partial and abstract representations of phenomenon (Harrison & Treagust, 2000; Wartofsky, 2012). Because scientific modeling draws heavily on the learner’s ideas about making sense of phenomena, this practice inherently pushes students to reason about the nature of scientific knowledge. Models can be expressed or conceptual (Giere, 2004; Gilbert, Boulter, & Rutherford, 1998), take a range of forms (Harrison & Treagust, 2000), and be intended for various purposes (Berland et al., 2016; Tregust, Chittleborough, & Mamiala, 2002). Within this study, I examine students’ expressed scientific models and the variety of purposes for which they were constructed.

A model cannot fully explain all elements of a phenomenon, and thus the purpose and cognitive agency of the model lies within the modeler (Giere, 2010; Harrison & Treagust, 2000; Wartofsky, 2012). Ergo, the modeler decides the bounds, purpose, and appropriate abstractions for the model, which, in the case
of explaining scientific phenomena enables the modeler to engage in more sophisticated cognitive reasoning about the phenomena. It is through making these choices that students reflect on the nature of science knowledge. Models therefore have the potential to stimulate complex reasoning about science epistemology, but also carry the risk of becoming a rote assignment when reflection is omitted (Schwarz et al., 2009; Treagust et al., 2002). Students who are tasked with using a model to answer questions, generate explanations, or make predictions must construct a model with greater cognitive agency than students who are simply drawing a picture of a plant cell or of a storm. The former enables students to decide the boundaries of the model, choose an appropriate abstraction to suit the purpose, and incorporate the invisible features that make up the substance of the science behind the phenomena; the latter provides an opportunity for students to exercise their artistic vision. The distinction of for versus of embodies the difference in these tasks (Passmore, Gouvea, & Giere, 2014). When students construct model for explaining a phenomenon, they engage in the same kinds of thinking and decision-making as scientists; when students construct models of a phenomenon, they merely recreate the visible features on paper. Framing of the modeling event that situates the purpose in explanation creates an opportunity for meaningful science engagement. In this paper, I examine how teacher modifications to the final model may influence student engagement in the knowledge construction.

**Meaningfulness.** As students engage with the scientific practices, their goals in working with the knowledge at hand fall along a continuum in which the
experience is meaningful to either the classroom community or to the scientific community (Berland et al., 2016; Figure 1). When an activity is meaningful to the scientific community, students may be collecting data about the moon phases in a way that reflects appropriate astronomy practice yet holds no value for the students beyond filling in a worksheet. Conversely, an activity that is meaningful to the classroom community would be one in which the students have a great deal of fun creating photosynthesis haikus but spend no time actively working to make sense of how and why photosynthesis happens. When classroom activities are framed at either pole, either student interest or scientific value is sacrificed, thus losing the power to engage students in complex scientific thinking. We define true meaningful engagement in the practice as having value to both communities, thus falling midway along this continuum (Berland et al., 2016).
Figure 1. Continuum of ways in which classrooms engage in scientific practices (Berland et al., 2016). Meaningful engagement in the practices in classrooms contains elements of meaningfulness to both the scientific community and to the classroom community.

The goal of the scientific practice of modeling is for students to engage in modeling that reflects scientific thought. As students construct a model, various decisions must be made about the components of the model and how those components support the goal of the model. When students reason about these decisions during modeling, they are engaging in epistemic thought about what goes into the model and why. As a whole, these ideas and the subsequent actions are referred to as epistemologies in practice (EIP) (Berland et al., 2016). Part of the EIP framework further elaborates on the epistemic considerations that students use as they construct a knowledge product. These epistemic considerations have been shown to be useful in both expert and novice knowledge building and are productive leverage points in understanding the variety of ways that students engage with their knowledge product (Berland et al., 2016).

Because students consider a wide range of ideas as they engage in knowledge building, the epistemic considerations are framed as questions that guide the decision-making process for students (Berland et al., 2016). The four epistemic considerations outlined by Berland et al. cover student thinking about the nature of their knowledge product, the ability of their knowledge product to be generalized to other ideas, the justification used to support their knowledge product, and the audience of their knowledge product (Table 1). While these epistemic considerations are applicable to the construction of various knowledge
products, we are specifically interested in how the classroom community attends to these ideas as they construct models.
<table>
<thead>
<tr>
<th>Epistemic Consideration</th>
<th>Range of Students’ Considerations</th>
</tr>
</thead>
</table>
| **What kind of answer should our knowledge product provide? (Nature of Account)** | • Our knowledge product should *describe* what happened in detail.  
• Our knowledge product should *explain how or why* something happened. In other words, it should articulate a step-by-step mechanism. |
| **How does our knowledge product relate to other scientific phenomena and ideas? (Generality)** | • Specific scientific phenomena do not relate to one another, so our knowledge product should characterize the specific nature of each individual phenomenon.  
• Generalized science ideas have little relationship to specific experiences or phenomena so our knowledge product should not connect across these ways of thinking.  
• Our knowledge products are created from and should explain a range of phenomena, so our knowledge product should show these connections. |
| **How do we justify the ideas in our knowledge products? (Justification)** | • We include the information in our knowledge products that others tell us to include (so it does not need to be justified).  
• We construct, evaluate, and justify our knowledge products using our interpretation of the available information (e.g., data, scientific theories, personal experiences, etc.) |
| **Who will use our knowledge products and how? (Audience)** | • Our knowledge product is for the teacher to evaluate our understanding.  
• We collaboratively construct and use our knowledge products with our audience. |

**Nature of Account: What kind of answer should my knowledge product provide?** In constructing a knowledge product, students must consider...
what counts as a sufficient answer (Berland et al., 2016). When students are tasked with answering a question, they need to decide the nature of the account they will provide. Will their account provide a detailed description of the phenomenon? Will it provide a causal explanation for the mechanism behind the phenomenon? Will it list the factors involved in the phenomenon? Consider the scenario in which students have been asked to construct a knowledge product that explains temperature differences on the first and third floors of a school. Some students might produce a detailed drawing of a school that uses red and blue colors to depict “heat” on the third floor and cooler air on the first. Other students might name air particles as an important factor in explaining temperature differences but fail to fully reason about the mechanism. Students engaged more meaningfully in the knowledge construction might provide a causal mechanism that explains how and why the temperature differences occur, naming and unpacking the factors involved in the phenomenon. As students navigate the knowledge building process, their choices regarding the nature of their answer can indicate the extent to which the students are meaningfully engaged in science learning.

**Generality: How does my knowledge product relate to other scientific phenomena and ideas?** As students construct and, most often, use their knowledge products, they consider how it can be generalized to other scenarios. Although generality is sometimes made explicit in the framing of the knowledge building (construct a model to explain condensation vs construct a model to explain why there is dew on the grass in the mornings), students can choose the
level of abstraction they feel is appropriate. In these situations, students may draw upon specific scenarios to provide evidence for their mechanistic account or they may generalize the scenario to an exemplar capable of explaining similar events. Meaningful learning is attainable in either case when students move beyond using the knowledge product as an exact replica of the event and are able to consider the limits of the knowledge product’s explanatory powers.

**Justification: How do I justify the ideas within my knowledge product?** This consideration focuses on two aspects of the students’ ability to support the ideas within their model: the source of the evidence and the reasoning students do about that evidence. The decision to identify a source of evidence in a model indicates that students are thinking about the need to consider the origin of knowledge. This behavior can be critical to students understanding the nature of scientific knowledge, yet the type of evidence to which students refer can indicate their ideas about how scientific knowledge is generated. Students who cite authoritative sources might similarly accept that science is a collection of facts, whereas students who cite empirical evidence might be more likely to recognize the constructivist nature of the field of science. Additionally, students who cite previous experiences might be reflective of their ability to generalize phenomena and make sense of patterns in everyday life. We see identification of a source of evidence as an indication of potential meaningfulness in the modeling activity, as it suggests the knowledge product was constructed with more cognitive agency than a rote artistic representation.
While it is a positive start, naming a source of evidence is not enough to establish a student’s engagement in meaningful science; students must further interpret that evidence and reason about its ability to justify the claim. Some students fail to understand this piece of justification, stating that they do not know how it can support the claim, only that it does. Students who are able to apply reasoning do so in a variety of ways. For some, they identify tenuous links to the empirical data but do not explicitly interpret the data, while others offer simple interpretations of the data. Sometimes students will provide complex interpretations of the data or even synthesize information from multiple sources. Students who provide both a source of evidence as well as reasoning about that evidence are often likely to do so because the modeling activity has been problematized in such a way as to necessitate elements of persuasion or argumentation, or simply because justification of knowledge has been prioritized in their classroom culture.

**Audience: Who will use my knowledge product and how?** As students are constructing their model and considering the various ways in which they could represent the phenomenon and justify the claims, they are also likely to be implicitly considering an audience for the model. Students’ perceived audience (or lack thereof) drives many of the epistemic decisions they make as they construct knowledge (Berland et al., 2016). In this consideration, students must make decisions about who will use their model (who), the purpose of the model with regard to that audience (why), and how that audience will use the model to achieve that purpose (how) (Berland et al., 2016).
The audience for a student’s model can be either explicit in the activity or implicit as the students make sense of the activity. For example, students might have been told that their models will be displayed at a school science night and should be constructed with parents and siblings in mind. When the audience is not made explicit, students might decide to cater to a specific audience, such as “We should use smaller words so that a sixth grader could understand it.” Alternatively, they may also draw conclusions about the audience based on the context of the activity, for example, “I included these terms because Ms. L gave us a list of things we needed to include”. In some cases, the audience is the classroom community as students take on a primary role in making sense of a puzzling phenomenon.

Students must then consider the driving purpose behind the model, or why they have constructed the model with a specific audience in mind. Student examples of this aspect of the consideration range from communicating ideas to sensemaking or persuading. For example, the class might have decided that the consensus model should be able to explain to younger student how and why a pendulum stops swinging. In this case, the students have established communication of ideas as a primary goal of the model. Conversely, a group of students might have made their model with the intention of convincing someone that lamprey caused the decline in the trout population. The purpose of the model with regard to the audience pushes students to include certain elements in their models and influences the level at which they are engaged in meaningful construction of knowledge.
Finally, in thinking about the audience for the model and the purpose behind it, students consider how the audience will engage with the model and the extent to which they should be involved in the construction and elaboration of ideas. Some students might see their model as a definitive explanatory tool that requires very little involvement on the part of the audience. In this case, the audience is a passive onlooker that need only see the model to be convinced or made aware; the student does not feel the need to work with the potential ideas of the audience to convince to teach. On the other hand, students can work with the ideas of the audience as fellow collaborators in the construction of knowledge. In this case, students think about opposing ideas that their audience might hold and how to work with those ideas to create a clearer or more persuasive knowledge product.

Together, these epistemic considerations represent a collection of decisions students make as they engage in a practice, and while they are not an exhaustive list, they tend to be in the foreground of student engagement in the practices. Although the examples provided above focus on how students attend to epistemologies, we are also interested in how the teacher attends to the epistemic considerations as she engages in discourse with the students during a practice embedded within the lesson. Teacher attendance to these ideas looks similar to the range of student responses shown here, and teacher prioritization of the epistemic considerations in the classroom discourse can influence the extent to which students prioritize them in their own thinking. Now that I have established the theoretical framework, the next challenge is understanding how
the framework fits into the larger network of current research on student epistemic thinking.

**Supporting students’ growth in epistemologies**

Although the Next Generation Science Standards call for engagement in science practices in classrooms, the reality of the implementation is varied in terms of meaningfulness (NRC, 2012). After engaging in a modeling unit that emphasized reasoning about evidence, students included more invisible features in their final explanatory models, held more complex understandings about the use of empirical evidence to support models, and became more sophisticated in how they view scientific models (Hokayem & Schwarz, 2013; Schwarz & White, 2005), indicating that meaningful instruction can support growth in student epistemologies. Interestingly, while students can become more sophisticated in their EIPs over the course of one unit of meaningful instruction, students do not necessarily experience growth to the same extent or in the same ways (Baek & Schwarz, 2015). We have also found that when instruction is not clearly framed by the curriculum or the teacher, students make their own assumptions about epistemological considerations and student growth in EIPs is less defined (Manger & Kenyon, 2016). These findings suggest that although students can experience growth in the EIPs when instruction scaffolds construction of meaning that is relevant to both the students and the discipline, more consistent growth likely occurs with intentional framing of this kind of meaningful learning. As student epistemologies can indicate their perceived or intended goal for the practice (Sandoval, 2005), classrooms in which student epistemic considerations
range widely indicates that the goal of the model was open to interpretation; namely that construction of meaning was individual rather than a group goal. Taken along with the knowledge that students and teachers often have different ideas about modeling (Grosslight, Unger, & Smith, 1991), these data suggest that the teacher plays a critical role in influencing sophisticated epistemic thinking in students.

Growth in epistemology is context dependent, and while curricular materials can provide a starting point for supporting student epistemic thinking, teachers remain the most valuable resource in terms of scaffolding student growth in science epistemologies (Chinn & Malhotra, 2002; Baek & Schwarz, 2015; Hammer & Elby, 2002; Sandoval & Morrison, 2003). Because modeling can become procedural without proper teacher scaffolding (Baek, Schwarz, Chen, Hoyakem, & Zhan, 2011), it is important that teachers have a solid understanding of the practices and their epistemological underpinnings. Furthermore, teacher framing of classroom events can have unintentional effects on students’ engagement in meaningful learning, despite including practices within the lessons (Berland & Hammer, 2012; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000). Teachers’ ideas about science and scientific practices influence the ways in which they scaffold their students during these activities (Zangori & Forbes, 2014), therefore teachers who devalue the epistemic nature of science will likely spend little time emphasizing it even when present within the curriculum. Clearly, the role of teachers in providing meaningful classroom science experiences is paramount.
Obstacles to meaningful engagement

Despite this knowledge, there are still a variety of obstacles to facilitating meaningful science learning in school, specifically with regard to supporting teachers. The classroom is a complex and often unpredictable place for teachers (Barnett & Hodson, 2001). Teachers generally have a limited understanding of scientific modeling and use a variety of approaches to modeling in the classroom, few of which support meaningful engagement (Danusso, Testa, & Vicentini, 2010; Justi & Gilbert, 2003; Justi & Van Driel, 2005; Magnusson, Krajcik, & Borko, 1999; Nelson & Davis, 2012; Oh & Oh, 2011; Van Driel & Verloop, 1999; Van Driel & Verloop, 2002; Windschitl & Thompson, 2006). These ideas about modeling might come from preservice teacher training, as teachers tend to approach inquiry in ways similar to how they were exposed during their preservice education (Windschitl, 2003; Windschitl & Thompson, 2006), suggesting a lack of appropriate support for science teachers at the start of their careers in terms of scientific practices. Moreover, many teachers have inadequate understandings of the nature of science and the role of practices in authentic science (Abd-El-Khalick & Lederman, 2000; Lederman, 1992). Inservice teachers instead often think of models as communication tools and emphasize their students’ final product rather than the sensemaking power behind it (Justi & Van Driel, 2005; Kenyon, Davis, & Hug, 2011; Nelson & Davis, 2012; Zangori, Forbes, & Biggers, 2013). When science epistemology has not played an important role in preservice education, it comes as no surprise that inservice teachers find value in the aspects of modeling that indicate concrete
growth in students' content learning. This can produce an incredible challenge in considering how to support engagement in the practice that is meaningful to the discipline and to students rather than meaningful to only one of those groups.

Even with professional development, many teachers continue to use modeling as a means to accomplish their own classroom goals such as content coverage, which might result in the activity aligning with either rote action or entertainment. After using a modeling software tool in the context of preservice education, some preservice teachers still were unsure of the link between scientific inquiry and scientific modeling (Schwarz, 2009). Despite an intervention, teachers still preferred using computer modeling programs that would be entertaining for students, regardless of the model's power for epistemic engagement (Schwarz, Meyer, & Sharma, 2007). These studies highlight the difficulty in shifting teacher beliefs about science and scientific practices toward more robust understandings of the role of science epistemology, yet some groups have seen success in this area. After an immersive experience in authentic science modeling, preservice teachers developed more sophisticated ideas about the practice of modeling (Crawford & Cullin, 2004). Others have found that as teachers become more advanced in their understanding of modeling, they follow unique trajectories, sometimes experiencing growth in breadth or depth in science epistemologies (Nelson & Davis, 2012). Although these shifts represent a positive trend toward more meaningful learning in the classroom, teachers often forgo authentic science because of the challenges it brings. Teachers who engaged in a science apprenticeship and subsequently
developed a more sophisticated understanding of the nature of science later abandoned their attempts to include meaningful science in their classroom, citing time, subjectivity, and the “messy” nature of the discipline as reasons why classroom science could not more closely reflect the discipline of science (Varelas, House, & Wenzel, 2004). For many, the goal of meaningful engagement in science is difficult, and because it does not align with the classic expectations of school science, teachers may readily abandon it.

**The contribution of this study**

With the turn to scientific practices comes a host of challenges in terms of implementation that is reflective of the discipline and captures the interest of students. Students can engage in authentic science and develop more sophisticated understandings of science epistemology (Schwarz et al., 2009), but these learning gains are more likely to be the result of careful instructional support than an accidental occurrence. The variety of obstacles facing teachers as they design and implement modeling practices in the classroom can result in activities that are merely masquerading as science and thus will not help students in developing an accurate idea of the discipline. This study is unique in that it will investigate the interactions of the teacher and students in several modeling units and how those interactions support or detract from meaningful engagement in science practices over the course of an entire unit. Specifically, understanding how the teacher and students interact to co-construct meaning through negotiation of roles and attendance to the epistemic considerations, and then how students apply that constructed meaning to their final model, will be
instrumental in supporting teachers and students in the future to construct meaning in the practice that is both authentic to the discipline and captures student buy-in. Furthermore, in studying the range of epistemic considerations students have as they engage in the different modeling units, we can gain a firmer grasp on the ways in which students respond to or challenge teacher framing of the classroom discourse. Using this information, we can support teachers in identifying and capitalizing on student engagement in a way that is productive to knowledge construction both in the classroom and as students build a knowledge product. Together with the knowledge from previous research, the information from this study will continue to add to the repertoire of discourse moves that would support teachers in facilitating meaningful science learning as they approach practices in the classroom.
Chapter 2: Methods

To study the interactions of the teacher and students and the ways in which they attend to the epistemic considerations, I am using a multiple case study methodology to compare three different modeling units taught by one middle school teacher. This particular methodology allows for a close examination of the three cases and the potential differences in support provided by the teacher. Discourse analysis and interview data will provide a deeper look at the microcosm of learning within each unit: the ways in which the teacher and students interact to construct meaning in the modeling activity, and the ways in which students apply that constructed meaning to their final model. This descriptive analysis will afford a detailed picture of how the teacher and students interact and attend to the epistemic considerations within each unit as well as the differences among the units. Thus, we will see on a small scale how the modeling practice was approached and attended to by the students and teachers as well as the larger tapestry of how differences in teacher supports can influence student engagement in the practice.

My main research question aims at understanding how the teacher is supporting students in a modeling curriculum. I want to know the ways in which she is interacting with the students and negotiating roles in the classroom to
support the students in epistemological understanding of the modeling practice. To answer this question, I have two subquestions to refine the goals of this research:

**RQa. How does the teacher engage with students in the classroom to co-construct meaning?**

To answer this question, I analyzed classroom discourse from three separate units in the students’ eighth grade year and specifically focused on the ideas of agency and attendance to the epistemic consideration. By using a multiple case study, I am afforded a look into three different occasions in which the students and the teacher must make sense of the modeling practice and how it is being used to help them explain the big idea of the unit. Discourse analysis focused on negotiation of agency: *who decides which ideas are salient?*, and attendance to epistemic considerations: *who initiates the attendance and how complex is it?* Together, these areas of investigation come together to characterize the nature of the constructed meaning of the activity. Additionally, by examining three separate units, I can look at the nuances that might be present in one cohort and how to optimize engagement in authentic science practice. As a reminder, in both research questions, my unit of analysis is the class, which contains the teacher and the students.

**RQb. How do students apply the co-constructed meaning to the knowledge product?**

Along with characterizing the constructed meaning in the classroom discourse, I analyzed how students refer to that meaning as they are engaged in
the construction of the final model in the unit. For this research question, I used student responses during reflective interviews to examine how students attended to the epistemic considerations as they discussed the final knowledge product. I want to know if students prioritized the same epistemic considerations in their final model as those prioritized in the classroom discourse and how their ideas about the final model relate to the constructed meaning in the classroom. I expect that discrepancies in students’ ideas about their final models and the constructed meaning from the classroom will inform ways in which students and teachers can be scaffolded in meaningful engagement in the practice.

**Research Design**

**Setting.** This study focuses on one science teacher, Mrs. L, and her eighth grade students in a small Midwestern school. The school has a strong focus on science and mathematics and enrolls students ranging from sixth grade to twelfth grade. In 2014, the school reported 25% free and reduced lunches. The 2016-2017 department of education Report Card indicated that 30% of the school’s population was non-white and 20% of the students came from economically disadvantaged households (Ohio School Report Cards). The school implements the IQWST curriculum from sixth to eighth grade and strongly encourages project based learning. The *Investigating and Questioning our World through Science and Technology* (IQWST) curriculum is a middle school curriculum that focuses on coherence of science ideas across units and years (Krajcik, Reiser, Sutherland, & Fortus, 2013). This curriculum uses scientific practices grounded by a driving question as a means to provide a
contextualization to the learning goals. Teacher educative materials are provided with the curriculum to support teachers in meaningful implementation of the lessons, which build upon the initial driving question through science investigations that culminate in the construction of a knowledge product (Shwartz et al., 2008). With this in mind, the school supports student-generated artifacts that are the result of collaboration from several subjects and can be displayed at school and public events. I discuss the participants and curricular context in depth below.

Participants. The teacher of interest, Mrs. L, was in her 9th year of teaching at the start of the study and had been teaching at the current site using the IQWST materials for 6 of those years. She received her Bachelors of Science in earth science and her MAT. At the start of the study, Mrs. L was familiar with the current curriculum and used it to teach both 7th and 8th grade science classes. At the start of our study, a large portion of our cohort, including the teacher, were familiar with each other and the culture of the school.

There were 34 total consenting student participants in the study. Of that number, 41% were entering their third year at the school at the start of the study and 50% were entering their second year at the school at the start of the study. Three students were new to the school when we began data collection, and 4 students left the study across the course of the data collection year for various reasons. I report these numbers to indicate that the majority of the students in our study were familiar with the curriculum and the expectation of knowledge
construction within, as the curriculum is used in all three years from 6th to 8th grade.

**Context.** The curriculum used by the teacher in this study, IQWST, has a strong focus on student knowledge building and the implementation of scientific practices throughout each unit and was designed to be used from sixth to eighth grade (Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008). Sequencing of the units within each grade level can be determined by the teacher, however each year was designed to build upon knowledge learned in the previous years and also build upon the scientific practices across all units. For example, the third sequence of Physics builds upon the concepts from Physics 2 and Physics 1, and incorporates scientific practices that are found in units from other sequences. Although a variety of practices are supported by IQWST, in particular, the practices of argumentation, explanation, and modeling are central to the curriculum, with each unit focusing on the construction of a knowledge product based on these practices. My research focuses specifically on three units: Earth Science 2, Biology 2, and Earth Science 3 because of the foregrounding of the modeling practice and the diverse array of knowledge products constructed by the students at the end of the units. Although some of these units originally called for the construction of scientific explanations, the teacher modified the lessons to include a heavy emphasis on model construction, with the culminating knowledge product being a model. I chose these units in particular because they emphasize modeling, were taught by same teacher in the same year, and resulted in final models that were unique across all three units.
Within each lesson, the scientific practice is framed by a driving question (Table 2) and students gather evidence to support the construction of their knowledge product through various experiments, activities, and readings supplied by the curriculum. The IQWST curriculum provided both student workbook materials as well as teacher educative materials that detail the practices, background knowledge, and planning materials. As previously mentioned, this particular cohort had experience with the IQWST curriculum; the teacher had six years of experience teaching with IQWST and 91% of the students had encountered at least one year of IQWST. Although I describe the units design in detail below, the particular contexts for classroom videos showcased in the results will be explained at length in Chapters 3-5.

Table 2
IQWST curriculum unit plans in order of completion

<table>
<thead>
<tr>
<th>Driving Question</th>
<th>Knowledge Product</th>
<th>Time Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Science 2</td>
<td>Model for explaining how air is heated; Model for explaining how a storm forms</td>
<td></td>
</tr>
<tr>
<td>What makes the weather change?</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Biology 2</td>
<td>Written explanation that answers the questions, &quot;What is going on in my body when I do certain activities?&quot; and &quot;Where is food used in my body?&quot;</td>
<td></td>
</tr>
<tr>
<td>What is going on inside me?</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Earth Science 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Earth Science 2. In this unit, spanning 8 lessons, students are presented with the driving question *What makes the weather change?* This unit was originally designed to take between 22 and 27 class periods and was divided into two learning sets in which students first answer the question *What causes a storm?* and then shift focus to global weather patterns by answering the question *Why is weather different from place to place?* Students worked to construct one model for each of these driving questions, using data gathered from investigations to gradually add more information to their model. A student workbook guided the lessons by providing readings, areas for note taking and data collection, and questions for sensemaking. Teacher educative materials were provided in the teacher edition of the workbooks. Information on scientific practices, literacy, classroom discourse, strategies for differentiation, and laboratory safety were also included in the front matter of the books. Pacing guides, discussion points, and overall learning goals were provided within each lesson, as teacher supports were designed specifically for each lesson.

The first half of the Earth Science 2 unit answering the question *What makes a storm?* was completed during the students’ 7th grade year. The shift to focus on global weather patterns and seasons provided a natural break in the material, and Learning Set 2, which focused on the question *Why is weather
different from place to place? was resumed at the start of the students’ eighth grade year. At this point, the students had constructed a model to explain how and why storms happen and had used this model to explain local weather patterns, but were unable to explain the drastic differences in weather across the globe. In this learning set, students analyzed data from cities around the world to understand the role of latitude on temperature and then consider earth’s shape as a reason for temperature differences. After an investigation in which students examined the effect of angle on light intensity, students constructed an explanation about why temperature varies with latitudes, but found that their explanation fails to explain the phenomenon of seasons. Using a variety of simulations about earth’s tilt, students combined this information to construct a model to explain seasonal temperature variations. The teacher modified the final lesson by asking students to construct a physical model to explain seasonal temperature variations using several common items provided in the classroom. After constructing this model, the teacher asked the students to re-create the model on paper as a means of helping them gather their thoughts for the end of the unit test.

**Biology 2.** The Biology 2 unit was completed immediately following the earth science 2 unit. This unit was divided into three learning sets that build upon each other to answer the driving question *What is going on inside me?* In this unit, students are challenged to think about the processes that enables the human body to perform tasks such as running and jumping, and to use concepts from earlier IQWST life science, chemistry, and physics units to make these
connections. Similar to the Earth Science 2 unit, teacher educative materials and student workbooks were provided as supports.

Learning set one started with the driving question *What is going on inside me?* and established foundational life science ideas by focusing on student observations about their own bodies, introducing the idea of cells and systems, and motivating students to make simple connections between these concepts. Students were also familiarized with the concept of systems and began to apply this information to the human body.

In learning set two, students followed the path of food from the mouth to becoming energy in the bloodstream. Using observations of chemical and mechanical digestion and by interpreting graphs of blood glucose levels, students constructed a mechanism for this pathway and applied it to their understanding of organ systems and digestive structures. Students then investigated how the glucose can enter cells and be used for energy by studying the permeability of onion cells and the effects of sugar on yeast cells. In later lessons, the students were introduced to the phenomenon of increased oxygen consumption with increased activity, and they then followed the path of oxygen through the body and uncovered its role in energy production.

The final learning set challenged students to make connections among the body systems in the unit to explain how and why increased activity impacts the body. The original unit plan called for students to construct a written explanation of where and how food is used in the body for energy. The students were then
asked to draw on their understandings of the body systems to explain the consequences of diseases or disruptions to normal bodily functions.

When planning for this particular unit, Mrs. L, along with another science teacher not associated with the study, asked for our help in modifying the unit to align better with the collaborative and project-based nature of the school. The teachers initially envisioned a project that would include educational efforts in science, language arts, and health and fitness classes, and would involve student-generated data collection with the collaboration of a researcher at a local university. The teachers also planned for the project to culminate with an infographic on the body systems that would be displayed at a public science night hosted by the school. To achieve these goals, the teachers planned a heavy emphasis on modeling throughout the lessons. I provide a more in-depth explanation of the changes Mrs. L and her colleague made to the curriculum in Chapter 4.

**Earth Science 3.** The Earth Science 3 unit asked the driving question *How is the Earth changing?* and was completed immediately after the Biology 2 unit. The unit was divided into four learning sets that asked students to examine and critique confirming and disconfirming evidence to support a mechanistic understanding of the phenomenon of plate tectonics. Central to the unit design was the idea that students should develop claims and construct explanations based on evidence, and later critique each other’s explanations. Teacher supports for this practice were embedded within the front matter of the unit text.
and build upon students’ previous knowledge of explanation construction that has been foregrounded in previous IQWST units.

In the first learning set, students were tasked with finding and making sense of patterns in volcano, earthquake, and elevation data. From this, students began to understand the link between geologic activity and plate boundaries. This introduction led into examining the same data that scientists used to develop the theory of continental drift and then building models to help explain how plate tectonics are changing. This also provided an opportunity to discuss the nature and limitations of models, evaluating and critiquing a variety of models depicting the same phenomenon.

The second learning set shifted the focus to understanding what causes the changes to earth’s surface. In these lessons, students investigated convection and conduction in solids and liquids and generalize their observations to fit a geologic scale. The students also revisited the earthquake and volcano data from the first lessons and apply their understanding of plate tectonics to the locations of activity and the surrounding plates. Students investigated the consequences of plate movement and the causes behind plate movement. In the third learning set, students used the data they have collected thus far to reason about the direction of plate movement. They then reasoned about the evidence in light of the principle of conservation of matter to construct scientific explanations that explain how plate material is recycled through the earth system as a result of plate movement.
In the fourth and final learning set, students would have constructed both models and explanations to describe how plate tectonics impacts earth’s surface. This learning set was removed from Mrs. L’s lesson plans, which I discuss in Chapter 5. As designed in the IQWST materials, after students had summarized their understandings using charts and cross-sectional models of earth’s layers, they would build a model and then construct an accompanying explanation.

**Data Collection.** I collected two sources of data over the course of the study: interviews and classroom video. Data collection began in 2015 in the students' eighth grade year and was completed in the same school year. Below I provide more detailed descriptions of the data sources.

**Classroom video.** I collected classroom video data at various time points throughout the units that corresponded to student work with a practice, such as modeling, argumentation, and explanation as described in the IQWST curriculum. Because this data set comes from a larger ongoing study examining student engagement in the practices, our access to classroom videos was limited to days in which the curriculum called for engagement in the practices of modeling, explanation-building, and argumentation. Thus, when the teacher removed a modeling or argumentation day from the lesson plan, as was frequent in Biology 2 and Earth Science 3, video data was not collected. While the data we did collect overlaps with our goals of understanding how the teacher and students co-constructed meaning during engagement in a practice, it limits our opportunity to understand the extent to which and the effects of the teacher revising the lessons. Again, although not essential to answering the research
questions posed within this dissertation, the information from the untaped classroom days could have been fruitful in making sense of some of the emergent patterns in the data. I discuss this later in Chapter 6.

Along with the classroom video, I took field notes for reference. For the purposes of this study, I am interested in those videos that include moments specifically grounded in student work with modeling, but may also include other practices. We collected between three and nine videos from each unit, depending on the nature of the classroom work in the practices and the extent to which the teacher removed work in the scientific practices from the lessons. On average, the length of the classroom practice engagement, and thus the taped video, was about 40 minutes each. In Earth Science 2, we collected and analyzed data from seven classroom days in the last half of the unit. In Biology 2, we collected and analyzed data from nine classroom days in the first half of the unit, as the second half was heavily modified to remove practice engagement. In Earth Science 3, we collected and analyzed data from the first three lessons, as the teacher specifically removed the practices from the remainder of the unit. I will describe the particulars of these classroom days in Chapters 3-5 in the context of the data analysis.

**Interviews.** We conducted semi-structured interviews with 18 focus students at the end of each unit. Interviews lasted between 5 and 20 minutes each and were grounded in the knowledge product students had constructed in that particular unit. To understand their attendance to the epistemic considerations and their application of the constructed meaning to their model,
we asked students to think about the epistemic decisions they had made as they were constructing their model and to reflect on the nature of their model compared to nature of the science they had been doing in class. Interview questions aimed at capturing student attendance to the epistemic considerations as they constructed their models included "Who do you think your knowledge product is for?" (Audience), "Could you use this model to explain something else?" (Generality), "Explain your model to me" (Nature of Account), and "What evidence did you use to support your model?" (Justification). To understand how their actual knowledge product compared with the engagement in practices in class, and thus their constructed meaning regarding that engagement, we asked students about the purpose of models in the class and their thoughts about construction of knowledge and meaning. For example, we asked students, “Why is it important to use models in class?,” “What do you consider to be good evidence?,” and “Why are discussions important?”

**Data Analysis.** We transcribed all video data verbatim and coded according to the framework described below using NVivo software. We achieved at least 85% inter-rater reliability for coding. Below I share the constant comparative coding decisions for each data source.

**Classroom video, open coding.** During initial coding, I examined the available classroom videos for moments in which the students were engaged in a scientific practice (NRC, 2012). For the Earth Science 2 unit, there were 7 classroom videos, for Biology 2 there were 7, and for Earth Science 3 there were 3 videos that fit these criteria. Within these moments, I open coded for
attendance to an epistemic consideration (Tables A1, A2, & A4) and emergent themes which answered the question *Who has epistemic authority in the classroom?* These emergent themes were later categorized during axial coding (Table A5).

**Classroom video, axial coding.** Next, I examined the patterns in emergent themes and epistemic considerations. From these patterns, I developed more specific codes regarding emergent epistemic agency themes including sensemaking, validity of new ideas, and task framing (Table A5). Within the category of sensemaking, I was concerned with who in the classroom was doing the cognitive work of making sense of connections among data and ideas. These episodes were characterized by the classroom participants actively trying to “figure out” what was happening with the phenomenon at hand. The theme of task framing emerged from episodes during which either the teacher or the students were setting the purpose of a classroom activity. The theme of validity of new ideas emerged from episodes during which students were asking questions or adding novel claims, and then how the teacher or other students responded to those new ideas.

**Classroom video, selective coding.** Finally, I used specific codes to categorize the classroom video data in terms of both attendance to epistemic considerations and negotiation of student epistemic agency. During selective coding for attendance to epistemic considerations, I coded audience, justification, and nature of account episodes for level of sophistication using the framework established by Berland et al. (2016). The specific coding framework is available.
in Tables A1, A2, and A4. Next, I selectively coded the epistemic agency categories by distinguishing between student-led and teacher-led episodes and episodes during which the teacher was either receptive to new student ideas or reasserted authority (Table A5).

**Interviews, open coding.** In total, there were 18 student interviews from the end of each unit, and I was specifically interested in how students attended to the epistemic considerations as they discussed their final model, as well as their ideas about construction of meaning. During initial coding, I identified episodes of attendance to the four epistemic considerations and flagged these episodes under the larger categories of audience, justification, and nature of account (Tables A1-A3). Additionally, I identified moments in which students were discussing ideas their models and modeling that did not fit in the coding rubric established by Berland et al. (2016).

**Interviews, axial coding.** More stringently, as I coded the interview data, I developed categories for student ideas about the use evidence that were not captured by the codes established by Berland et al. (2016). Additionally, as students were discussing their models and their ideas about modeling in the classroom, I developed coding categories for these sentiments in terms of the construction, use, and evaluation of models in general in the classroom (Table A6).

**Interviews, selective coding.** Finally, I coded the episodes flagged with epistemic consideration attendance according to the specific EC coding rubric
(Tables A1-A3). I coded student ideas about the use of evidence in the models using coding categories similar to those found in the EC coding rubric (Table A6). These codes will be useful as I compare student ideas about salient sources of evidence with the evidence they actually used as they constructed their models. I further developed coding categories in terms of student construction, use, and evaluation of models in the classroom (Table A6).

**Trustworthiness**

In qualitative research, it is essential to address the trustworthiness of the data being presented (Shenton, 2004). My research comes from a larger, more established study, which means that several data sources were shared. In this section, I explain steps taken both in my research and the larger study that support the trustworthiness of the findings.

**Credibility.** To achieve the parallel of internal validity within this study, I have employed several methods of credibility according to Shenton (2004). These methods are listed and described below.

**Adoption of well-established qualitative research methods.** In this study, I use a multiple case study methodology and gathered data using well-established data collection methods of semi-structured interviews and classroom video transcripts.

**Development of a familiarity with the culture being studied.** Prior to collecting the data being analyzed in this particular research study, I had been involved in data collection with the same school, students, and teacher for a year.
prior as part of the larger longitudinal study in this setting. Because the larger study took place in the same context as my own data collection, and in some aspects overlapped with the data collection, I developed a strong familiarity with the students and teacher, as well as the overall school culture. This was beneficial for not only gaining an understanding of the context, but also for cultivating a mutual sense of respect and trust between researchers and participants.

**Random sampling.** The 18 focus students selected for interviews were chosen as a representative sample of the consenting student population. These students were representative of the larger classroom population based on gender, socioeconomic status, and student achievement. Because this data came from a larger longitudinal data set, we took into account the number of years the students had attended this school and sampled equally from these pools.

**Tactics to ensure honesty in informants.** To ensure that participants were comfortable and honest in the student interviews, the interviewers assured students that there were no right or wrong answers, that their responses would not be shared with the teacher, and that they had the right to terminate their participation at any point.

**Peer scrutiny of the research project.** Because this data set came largely from a more comprehensive longitudinal study, multiple members of the research group reviewed and revised the project at various points throughout the
overarching study. A team of researchers across several universities carefully
designed and enacted this five-year NSF-funded project and the associated data
collection protocols. Thus, it is with confidence that we conducted the interviews
and selected the days for classroom video collection for this smaller portion of
that project.

Transferability. One of the loudest criticisms of qualitative research findings
comes from questioning its ability to be effortlessly transferred to other situations.
This particular school, teacher, and students are unique. The teacher has her
own goals, potentially at odds with those of the curriculum, a unique background
and experiences, and interacts with her students in ways distinct from other
teachers because she is an individual. Similarly, the students come to school
with a host of experiences, emotions, social interactions, etc. that are exclusive
to them as individuals. To expect the exact same interactions at the same
intervals by similar individuals at another location is nonsensical; however, there
are important aspects of this research that are transferable to other students in
other schools, perhaps in contexts that look quite dissimilar to the ones seen
here. Based on the results from this study, I can argue that students and
teachers in a variety of contexts are capable of co-constructing sophisticated
epistemic meaning in the classroom under certain conditions which I will expound
upon in Chapters 3-5, and more explicitly in Chapter 6. Based on the length and
volume of the classroom data analyzed, I can argue that certain discourse moves
were either more or less productive in eliciting sophisticated student responses.
Furthermore, based on the number of student interviews and the emergent
patterns within those interviews, I can make claims about student perceptions and use of the co-constructed meaning from their classroom experiences. Because of the richness of this study, both in volume of data and analysis methods, I can identify emergent themes in each of the cases, form supported speculations about the source of these themes, and make claims regarding the implications of these themes for a variety of classroom contexts.

**Dependability.** To address the dependability, or reliability, of this research project, not only have I maintained transparency in methods and context of the study, but also, I include detailed coding rubrics in the supplemental information. Interrater reliability across three coders was between 85 and 90%.

**Confirmability.** Because I report on emergent themes across the three case studies and offer suggestions as to situations that may have contributed to those themes, it is important to also comment on the objectivity of this study. The data presented in this dissertation comes from a larger set of longitudinal data; the methods, criteria for choosing classroom days to record, and interview protocol used here came from the aforementioned project. The choice to more closely examine these three particular units came as a result of being in the classroom and noticing the ways in which the teacher modified—or did not modify—the lessons. I wanted to objectively analyze the variety of ways the teacher supported students as they were constructing these models, both in the classroom as the teacher and students navigated scientific practices and then how the students negotiated the constructed meaning regarding the practice with their final modeling task. So as not to manipulate the findings, I used established
coding rubrics to guide my analysis of the epistemic considerations and then extensively refined and sought feedback on codes developed from emergent themes on student agency.

**Scope of results**

I discuss the results of this study at length in the remaining chapters of this dissertation. In Chapters 3, 4, and 5, I report on each of the units studied: how the teacher and students worked together to co-construct meaning in the classroom, and how students applied this co-constructed meaning to their final models. I answer RQa in each respective chapter by examining the classroom video data, and RQb by examining the student interviews. To answer the larger question, *How did the teacher support students across a modeling unit?*, I discuss the overarching themes from the units and reflect on how aspects of the classroom environment may have contributed to the patterns in the ways students view their final models. I present this information in Chapter 6. As a reminder, my unit of analysis in this study is the classroom community.
Chapter 3: Earth Science 2

In this chapter, I analyze one of the cases from the multiple case study to answer the driving question: How does the teacher support students in a modeling curriculum? To answer this, I will first examine how the teacher and students co-construct meaning in the classroom as they engage in the scientific practice of modeling, and then compare it to how students apply that co-constructed meaning as they consider their final models. In this particular unit, Mrs. L and her students worked together to co-construct meaning that draws upon both scientifically authentic and personally relevant sources. We believe that students then applied this meaning to their final models, as is evident in how they discuss the construction and use of those knowledge products (Figure 2). Below I give a brief account of how we approached the analysis of co-constructed classroom meaning and applied final model meaning as well a summary of those findings.

- Audience. Who will use our model and how? In this unit, Mrs. L and the students co-constructed meaning in the classroom that prioritized the goals of knowledge products as informing or making sense of ideas. This meaning was applied by the students in their final models.
• *Justification. How do we justify the ideas in our model?* In the classroom, data was the most frequently cited source in the classroom, and discourse interactions around justification were mainly at levels 1, 2, or occasionally 4. Data and authoritative sources were the most frequently used sources by students in their final models, and students tended to justify at levels 0, 1, or 2.

• *Nature of account. What kind of answer should our model provide?* The co-constructed classroom meaning valued both students and the teacher as authors of the mechanistic account, meaning that both groups attended to the mechanistic unpacking of the phenomenon in relatively equal levels. Students applied this meaning to their final models as they reasoned about the phenomenon at levels 4 or 5.

• *Student Agency. Students exercised their epistemic agency in the classroom by asking questions, responding to peers in whole-class interactions, and attending to the epistemic considerations without prompting from Mrs. L. In turn, Mrs. L provided space for these interactions to occur.*

These findings are represented in Figure 2, which was generated using the patterns in attendance to epistemic considerations in the classroom discourse and student reflective interviews.
Figure 2. Classroom co-constructed meaning, the teacher approach to the final models (consistent with curricular design), and how the students applied meaning to their final models in the Earth Science 2 unit.

These attendance patterns were made evident using the coding rubrics (Appendix). For example, the three epistemic considerations (Audience, Justification, and Nature of Account), found as column headers in both the classroom co-constructed meaning and the meaning applied to the final model, are followed by the different coding categories in subsequent rows. Below the audience consideration heading, five categories are listed starting with Inform and ending with Persuade, which reflect the five coding categories in our rubric with regard to the purpose of the model. These categories are listed from top to bottom in order of increasing sophistication. Inform (to demonstrate or inform the audience), a less sophisticated goal and Sensemake (to make sense of ideas individually or together), a more sophisticated goal, are highlighted in the classroom co-constructed meaning, indicating that these two categories were the most frequently cited goals in the classroom. This pattern in audience attendance was also repeated in the meaning students applied to their final models.

In examining attendance to justification, we look at two aspects: the source of the evidence and the reasoning students do about that evidence (Figure 2). In the classroom discourse, Data (classroom activity or empirical data)
were most frequently used, whereas in students’ final models, Authoritative sources (teacher, Google, book, etc.) were cited along with Data. Explanations of the remaining categories can be found in the Appendix. There is no hierarchy in order of sources. With regard to students’ reasoning about the sources, I list the coding categories from 0 to 4, with level 4 being the most sophisticated. Levels 1 (identifies relevant information), 2 (provides a simple interpretation), and 4 (provides a complex interpretation including chaining claims or a rebuttal) were the most common in the classroom co-constructed meaning. Levels 1 and 2 were most common as students reflected upon the applied meaning. More detailed examples of coding rubrics can be found in the Appendix.

Attendance to nature of account is represented differently in the classroom meaning and the applied meaning (Figure 2). In the classroom co-constructed meaning, I simplified the categories to only include the group (teacher or students) responsible for mechanistic unpacking of a phenomena. Both categories are highlighted in this unit to indicate joint efforts in mechanistic reasoning. In the applied meaning, I included each coding category as students unpacked the phenomenon in their final models, listing the categories from top to bottom in order of increasing sophistication. In this unit, students frequently were able to name 2 and unpack at least one of the factors involved in explaining the phenomenon.

I represented student agency in the classroom using a border around the classroom co-constructed meaning rectangle (Figure 2). Student agency occurs when students attend to the epistemic considerations unprompted and push for
cognitive authority in the classroom, or when Mrs. L recognizes these efforts. The solid black line between the two rectangles indicates that Mrs. L’s approach to the final model was a continuation of the knowledge products students had been constructing in class.

I will present and discuss data from the classroom video to support the claim of scientifically and personally authentic co-constructed meaning, and provide examples of how Mrs. L and the students attended to the epistemic considerations in the classroom in sophisticated ways. Furthermore, I will provide examples of student epistemic agency that I believe exemplify personal buy-in to epistemic thinking and also contributed to the co-construction of scientifically authentic meaning in the classroom on the part of the students. Then, I will present and discuss data from the student interviews to support the claim that the co-constructed classroom meaning was applied as students constructed their final models for explaining seasonal variation in temperature. This data draws upon student attendance to the epistemic considerations as they discussed their models in an interview setting.

**Data Summary**

In order to provide the context for understanding the data, I begin this chapter by explaining the content of the classroom videos, the design of the curriculum, and the ways in which the teacher modified the lesson plans. While I briefly covered a portion of this material in Chapter 2, the descriptions I give here are much more detailed and specific to the three classroom videotape days on which I centered my analysis. This information then leads into an in-depth
analysis of those three classroom days in which the students were engaged in practices and the student interviews that occurred at the end of the unit.

**IQWST unit design.** I collected and analyzed videos from seven classroom days in the Earth Science 2 unit. As a reminder, this unit was divided into two learning sets: the first, understanding how storms form, was completed in the spring of the students’ seventh grade year; the second, understanding how and why seasons occur, was planned to be completed as the first unit of the students’ eighth grade year. This unit division of similar topics provided a natural break between school years and allowed for new students to the school to be easily acclimated to a new driving question along with the other students. To help remind students of how and why storms form, the teacher scaffolded a review exercise in which the students re-constructed their storm explanation as a class. This activity lasted about three days and is not included in my data set. Because my focus is on the eighth grade year and the ways in which this particular cohort of teacher and students co-construct meaning, I started my data collection at the onset of the second learning set, which began with Lesson 7.

Although I analyzed data from all seven days, I will focus my discussion in this dissertation on three particular videos, as these three not only provide highlights of all the epistemic considerations, but also, the patterns of attendance to epistemic considerations are consistent across classroom days such that I am confident in the emergent themes. Additionally, focusing on a smaller portion of the classroom data can convey more strongly the pervasive culture and meaning co-constructed in a given class day. Attendance to epistemic considerations,
videotape duration, and class activities are presented in Table 3. I chose these three classroom days for in-depth data analysis because there was relatively consistent attendance to the epistemic considerations relative to taping time, the students were generally on-task and engaged in whole-class discussions, and there were a variety of different episodes to examine for each day and EC. Below, I provide detailed descriptions of the context for these three classroom days.

Table 3

The nature of classroom activities and attendance to Epistemic Considerations on three videotaping days in the Earth Science 2 unit

<table>
<thead>
<tr>
<th>Epistemic Consideration</th>
<th>Lesson 7-5 Day 2</th>
<th>Lesson 7-5 Day 3</th>
<th>Lesson 8-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration (Minutes)</td>
<td>Episodes</td>
<td>Duration (Minutes)</td>
</tr>
<tr>
<td>Audience</td>
<td>14</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>Justification</td>
<td>11</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Nature of Account</td>
<td>10</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td><strong>Nature of Activities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off-Task</td>
<td>0</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Group work</td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Whole-Class Discussion</td>
<td>29</td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>Individual work</td>
<td>0</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Total Time</td>
<td>29</td>
<td></td>
<td>52</td>
</tr>
</tbody>
</table>

**Lesson 7-5, Day 2.** On this particular classroom day, the lesson started with students constructing an explanation to explain why the temperature is different at varying latitudes. On Day 1 of Lesson 7.5, which occurred
immediately preceding this day, the students and teacher were summarizing the big ideas from Lessons 7.3 and 7.4 and were discussing the changes in light intensity with angle based on what they had observed in the Chinese lantern activity. This hypothetical and informal activity provided students with enough evidence to challenge their ideas about tilt and allowed them to see the necessity of asking new questions about temperature variation and latitude. This particular classroom video was a continuation of that discussion as the class was finally ready to answer the driving question for Lesson 7.5: *Why does temperature vary at different locations?*

Mrs. L began Day 2 of this lesson by preparing to write a consensus explanation on the board. She prompted students with the driving question, and then framed the work as a collaboration when she said, “Where should we start?” The students brainstormed different ideas and then began to construct an initial explanation that Mrs. L wrote on the board according to input from the class. The entire class period was spent constructing this consensus explanation piece by piece, with the class reorganizing claims, synthesizing evidence, and working on convincing reasoning, and eventually the students decided on a cohesive flow for the explanation. At that point, the students were instructed to copy the complete consensus explanation in their own notes; this activity concludes the video. Throughout the period, both Mrs. L and the students attended to the epistemic considerations of audience, justification, and nature of account, and negotiated legitimacy of roles and ideas. I will discuss attendance to the epistemic considerations and epistemic agency later in this chapter.
Lesson 7-5, Day 3. Part of the students’ homework from Lesson 7-5, Day 2 was to individually construct a “diagram” to accompany the class consensus explanation. The wording of this assignment was intentionally vague; students could construct an explanatory diagrammatic model or they might simply draw a picture to illustrate the earth. Students were given this assignment at the end of Day 2, on a Friday, and were given some time at the beginning of Day 3, a Monday, to add any finishing touches. At the beginning of this particular day, Mrs. L started by asking students what kinds of things should be included in this “picture,” and students listed a few components they found essential to their diagram. It was made clear that the items on this list are not mandatory: “we have a preliminary list and just because the words are up here doesn't mean you have to include them. These are things that you guys think you would like to have in there, but not everybody listed every single one of these words. So, as you're working on your diagram on page 31, you might want to look at these words, but you can-these are like…suggestions. They’re not mandatory.”

After giving the students a few minutes to finalize their diagrams, Mrs. L invited several students to share their models and for the class to briefly comment on whether or not the diagram contained the terms from the list, simply to indicate that the list was a good start in thinking about the features necessary to explain temperature differences. Mrs. L then transitioned to the next question on their homework assignment, which posed the question: Is this diagram a model? Students shared ideas about their illustrations and about models in general before moving on to Lesson 8-1 in which they were visualizing and
making observations about temperature data using a computer simulation. The remainder of the class period and video is spent working with this data, both in graphing and making sense of it as a class.

**Lesson 8-1.** This classroom day immediately followed the end of Lesson 7.5, Day 3, and began with the teacher guiding the students in a sensemaking discussion about the visualization of the graphs the students had made previously. During this shorter videotaping day, the students and teacher engaged in the practice of analyzing and interpreting data. Along with making sense of the graphs, Mrs. L supported the students in constructing a mechanistic account of the temperature fluctuations using the data at hand. Lesson 8-1 concluded as Mrs. L handed out printed pages for the upcoming activity.

**Teacher Approaches to the Unit.** In the Earth Science 2 unit, Mrs. L followed and executed the unit closely to the intended plans in the IQWST curriculum. It is quite common for teachers to modify lessons according to the needs of their students, and it is possible—even likely—that Mrs. L strayed from the prompts in small ways throughout the unit. She did not, however, remove or replace entire lessons, particularly those in which students were to be engaged in a practice. This was made obvious to us via our videotaping schedule, which revolved around lessons that included a practice. The fact that we did not need to modify or remove taping days indicated that all lessons involving a practice were implemented as scheduled. Again, this is not to say that Mrs. L did not modify smaller pieces of the lessons, such as introducing a relevant website or news story, or making changes to in- or out-of-class assignments; for the purposes of
data collection for this study and the larger project, I am most interested in the ways in which the teacher made major changes to the lessons involving a practice.

Although Mrs. L did not remove practices from the unit, she did make one addition to the end of the unit. Lesson 8 calls for students to construct a diagrammatic model of seasonal variation in temperature; because her students were struggling to understand how the concept of tilt contributed to seasonal temperature changes, Mrs. L added an activity in which students constructed a 3-dimensional model of the phenomenon before constructing their final model. In this activity, the students worked in groups and used common household items to model the positions of the earth relative to the sun in each season. Students used tennis balls (the sun), ping-pong balls on pencils (tilted earth), and a hula hoop (earth’s orbit) to make sense of the role of tilt. The class then came together and Mrs. L helped the class to verbalize the ways in which tilt impacted the light intensity in the hemispheres in each season. After this activity, Mrs. L asked the students to recreate their model as a 2-dimensional tool for gathering their ideas and explaining tilt, which closely matched the IQWST prompt for this activity in which students were tasked with modeling *How does the earth move?*

**Analysis of Findings**

Now that I have introduced the particular context for the data I am foregrounding as I discuss the results, I will shift to using these three video days to answer specifically how the teacher supported the students across the Earth Science 2 unit. In answering my research questions, I will focus on how the
teacher and students co-constructed meaning in the classroom as they engaged in practices. Later, I will compare that to how the students applied meaning as they constructed and discussed their final model at the end of the unit.

**Classroom Co-Constructed Meaning.** The following describes how the teacher and students worked together in the classroom to co-construct meaning around and within a practice. In this section, I highlight episodes from the three lessons described earlier; recall that the patterns within these lessons are representative of the larger data set from this unit. Overall, based on attendance to the epistemic considerations and the negotiation of student agency, the students and the teacher co-constructed meaning that was both authentic to the discipline of science and valid to the classroom community. Thus, we consider this kind of co-construction to be meaningful engagement in the practices. Later in the chapter I will unpack how the negotiation of roles via student epistemic agency; for now, I turn to an analysis of epistemic consideration attendance in the classroom.

**Epistemic considerations.** This section details the students’ and teacher’s attendance to the epistemic considerations. Based on the level of complexity of the student episodes and the frequency of attendance in the classroom (Figure 2), I argue that the attendance to the epistemic considerations in the classroom was not only sophisticated, but also contributed to the co-construction of authentic meaning. Although I will discuss student agency in the next section, these two pieces make up the co-constructed meaning. Below I provide evidence from both the teacher and the students in the classroom to
support the claim that together the students and teacher co-constructed meaning that prioritizes epistemic thinking.

*Audience: My model is to inform and make sense of ideas.* When Mrs. L and the students attended to audience in the Earth Science 2 unit, they mainly considered the “why” of the practice to be for informing or sensemaking (Figure 2). While they had a variety of ideas about “who” their audience was and “how” the knowledge product could be used, there seemed to be clear framing of the knowledge product and the engagement in the practice as sensemaking, at least in the moment of engagement. In many ways, this framing comes from the teacher.

<table>
<thead>
<tr>
<th>1Mrs. L</th>
<th>It travels in straight lines. That’s really important to realize. The only time we get indirect light from the sun would be when light shines on…</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Students</td>
<td>The moon.</td>
</tr>
<tr>
<td>3Mrs. L</td>
<td>…the moon and it reflects off the moon towards the Earth, but is the moon part of our explanation? Were we looking at the moon phases to try to figure out why some places are hotter than others? No. That would be indirect light beams. So, do you want to answer that? I still wanna know why do some places up here get lower intensity light. The light is not hitting it perpendicularly, whereas this gets light coming at a perpendicular angle.</td>
</tr>
</tbody>
</table>

**Episode 1**

The first episode came about as Mrs. L asked the students to explain why some places on the earth are hotter than others. One student gave a response in which he referenced “indirect sunlight,” and Mrs. L is now addressing the terminology in Episode 1. It is important to her that the students understand the difference between using the word “indirect” to describe sunlight that is less intense due to the angle, and Mrs. L used this moment to help them to see why
that term could be confusing. In line 1, she explained this difference and reminded the students that indirect sunlight comes from sun reflecting off the moon’s surface. She then asked the students in line 3, “Were we looking at the moon phases to figure out why some places are hotter than others?” In this line, she was both framing the previous tasks as “figuring out” and referring to evidence, both in the hypothetical sense and in the real sense via the data they actually collected. I will discuss this briefly in the Justification section. Mrs. L then went on to say that she still wants to know the answer to the driving question. Although she explicitly referred to herself as wanting to know the answer, we see this as still being framed as sensemaking. The “right” answer is not a simple known response, but rather an explanation that students are still on the path to figuring out. Thus, the teacher was supporting the students in this particular episode to think about the activities in the past and the present as a collective sensemaking venture.

<p>| 1Mrs. L | Okay. So now that we know that, I think we can start asking- because I keep wanting to back up, you know, like why is this happening? Well, why is this happening? Well, why is this happening? So why is temperature varied with latitude? |
| 2Pandora | Because since the Earth is round like it has that curve. |
| 3Mrs. L | So maybe we start there. Since the Earth is round- Don’t write yet what I’m writing down because you might decide you want to change it. I want your input. I do not want me telling you what to write. I want you explaining to me. And what you have to think about is like who’s the audience of this explanation? When you explain this this in your own words why temperature varies with latitude, who are you explaining this to? |
| 4Percy | Dr. K |</p>
<table>
<thead>
<tr>
<th>Line</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mrs. L</td>
<td>Dr. K. Does that change the way you might explain things if we were to show this to a university professor who has a doctorate? So, Freya thinks her audience is a 6th grader and you think your audience is a college professor. Would that change the way you explain?</td>
</tr>
<tr>
<td>Percy</td>
<td>No</td>
</tr>
<tr>
<td>Mrs. L</td>
<td>Lindsay says yes. How would you change your explanation if you were explaining it to an adult versus a student?</td>
</tr>
<tr>
<td>Lindsay</td>
<td>Because the adults know what they're doing?...Because they [6th graders] don’t have the background information that we have in 7th grade.</td>
</tr>
<tr>
<td>Mrs. L</td>
<td>So how does that change your-what you’re going to do when you’re explaining it.</td>
</tr>
<tr>
<td>Lindsay</td>
<td>You have to look for- you’d have to what we just did about the light intensity.</td>
</tr>
<tr>
<td>Mrs. L</td>
<td>So, what Lindsay is saying is if you had to, uh, explain this to a sixth grader who doesn’t have this background knowledge, you would have to be more detailed. So, uh, Percy, if you were explaining it to Dr. K, would you change the way you explain it based on what Lindsay just said?</td>
</tr>
<tr>
<td>Percy</td>
<td>Um, I would make it, like, explain it like if you're going to write to a sixth grader you would make it simple, like you would explain everything and explain how it works and all that. If you're going to write it to a professor, you're pretty much going to have to do the same thing. Explain why you think it, how it works and everything.</td>
</tr>
<tr>
<td>Mrs. L</td>
<td>So you think your explanation would be very similar?</td>
</tr>
<tr>
<td>Percy</td>
<td>Yeah. Because people work the same way.</td>
</tr>
<tr>
<td>Mrs. L</td>
<td>Okay, because we’re all people and we still want to know how-why. We want to understand clearly.</td>
</tr>
</tbody>
</table>

**Episode 2**

In episode 2, not only was there implicit teacher framing of the activity as a sensemaking endeavor, but also the teacher was explicitly asking for student input regarding the intended audience for the consensus explanation. In line 1, Mrs. L framed the task as a classroom sensemaking activity when she said, “I
think we can start asking…" and then began prompting students to answer the driving question. Pandora responded in line 2 by providing a start to the account of the phenomenon. Mrs. L began to write Pandora’s ideas on the board, reminding students in line 4 not to copy this until they are all satisfied with the explanation. She then further framed this activity as one in which the students should be active explanatory thinkers. In line 3, Mrs. L said, “I do not want me telling you what to write. I want you explaining to me,” indicating there is a difference between “telling” and “explaining.” It seems that her goal in this was to encourage students to work together to explain this phenomenon of temperature differences rather than having a few individuals spout out “the right answer.” Although it seems she was at this point placing herself in the seat of the audience, she was ultimately attempting to move the students from passive “telling” to more active explaining that considers the needs and ideas of the audience. In this, Mrs. L was tacitly encouraging her students to attend to the audience as they engaged in a practice.

To add to this reframing from telling to explaining, Mrs. L then asked the students who they thought their audience was. Later in line 3, she expressly told the students that they must consider their audience as they write an explanation, then asked them to share their ideas about the audience for this particular explanation. Freya said her intended audience would be sixth graders (indicated by the teacher in line 5), while Percy, in line 4 said a college professor was his audience. In line 5, Mrs. L took this a step further and asked the students if they
would make any changes to their explanation to meet the needs of their intended audience; Percy and Lindsay had conflicting ideas.

From lines 8 to 11, Lindsay explained the differences between adults and sixth graders that would cause her to change her model depending on the audience. Adults, she said, “know what [they’re] doing” and have a basic understanding of the world that sixth graders lack, thus her explanation could omit certain redundant features. On the other hand, sixth graders do not possess the “background knowledge” that an adult, or even eighth grader, has, and so she would include certain information in the explanation to support the sixth grader’s understanding. Specifically, Lindsay said in line 10 that she would need to include “what we just did with the light intensity.” This is interesting because she not only indicated that sixth graders would need additional information, but she also indicated exactly what information she would recommend for them, and in the process, she attended to the epistemic consideration of justification. The activity that Lindsay referenced here is one in which the students collected data with a Chinese lantern and a lux meter to determine which latitudes on the earth get the most intense light. Although Lindsay failed to reason about this evidence in a sophisticated way, her dual attendance to both audience and justification indicates a complex understanding of the ways in which she should modify her explanation in response to a changing audience.

On the other hand, Percy indicated that he would not need to alter his explanations at all to fit the needs of either a sixth grade or an adult audience. Mrs. L asked him to be specific, and in line 12, he explained that while his
explanation for a sixth grader might include simpler terminology, the basics of the explanation would remain the same. He even went on to be specific about these basic ideas: what you think, why you think it, and how it works. Interestingly, this follows the general outline for an explanation given to students: claim, evidence, and reasoning. Thus, we can see here that Percy had not only bought into the structure of an explanation, he also believed this structure to be effective regardless of the audience “because people work the same way.” Another interesting aspect of this episode is that while Mrs. L allowed a variety of students to share their opposing ideas about potential audience, she refrained from favoring one idea over another, thus allowing students to be able to express and hold certain epistemic ideas without needing to be correct. Additionally, although this conversation brought a variety of audience ideas to the table, the action of constructing the consensus explanation remained a sensemaking, class-centered one, as the teacher gave no indication of a “true” audience and included the caveat “when you explain this...in your own words” in line 3 when she took the students down the audience conversation path.

| 1Mrs. L | The goal is what? Why are we doing all this? Like, what's the whole point of doing this in the first place? Why are we writing explanations; why are we making models? What do you think's going on here? Keshawn? Does it matter which one you like as long as you...? |
| 2Keshawn | Learn from it. |
| 3Mrs. L | Learn from it. The whole goal is to learn. |

Episode 3

Finally, in episode 3, which took place on another class day, we again see the discussion emphasizing the role of modeling and explanation-building in
terms of helping the students make sense of ideas. Prior to this particular exchange, the class had been discussing whether or not a diagram they had constructed to go along with their explanation was an explanatory model or simply a picture. Most of the students had agreed that what they had drawn was indeed a model because it was explaining what was happening in the written description, possibly for people who might have trouble understanding one or the other. One student mentioned she prefers writing explanations, and another said he would rather have the model to help him understand. After that, Mrs. L asked the students what the goal of building models and explanations in class is, and Keshawn responded in line 2, “Learn from it.” This exchange is important because both the students and the teacher were agreeing on a purpose for models in the classroom: sensemaking, which we consider to be a more sophisticated use compared models that simply demonstrate. Using a scale model to show students the orbit of the earth requires only passive involvement of the learner; these models are often common to classrooms and students are well acquainted with this type of tool. To see Keshawn agreeing with Mrs. L that students build models and explanations in school to learn represents a positive role of modeling in this classroom.

Overall, in the Earth Science 2 unit, the students and teacher not only attended to audience spontaneously, but they also did so in way that reflected rich engagement in the epistemic consideration. Not only did the students respond to the Mrs. L’s framing of the classroom practices as part of knowledge building, but they could also specify ways to modify their model to inform various
types of audiences. The responses seen here represent meaningful attendance to audience.

**Justification: We justify the ideas in our model with data.** In the Earth Science 2 unit, the students and teacher frequently attended to the epistemic consideration of justification. Students spent time in each of the three highlighted videos justifying the ideas in their explanation using evidence they had collected throughout the unit. In some cases, the students attended to justification spontaneously and with complex reasoning; other times, the teacher prompted students to include evidence or heavily directed the reasoning the students were doing. Regardless, justification, specifically using empirical data, was prioritized in this Earth Science 2 unit (Figure 2).

In episode 4, we return to an exchange from earlier in which Mrs. L framed the present and past activities as sensemaking. As a reminder, the students were engaged in forming an initial explanation about why temperature varies with latitude, and upon Scott’s use of the term “indirect light,” Mrs. L referenced an activity from the past and replaced their examination of sunlight with that of moonlight. In doing so, Mrs. L not only provided a hypothetical source of data (moon phases) as nonsensical in terms of figuring out the phenomenon, but she also refocused the students on the relevant data that will help them make sense of the ideas at hand. In line 1, Mrs. L reminded the students of the angles of light on different locations on earth and asked students to make claims about why that might be.

| Mrs. L | …the moon and it reflects off the moon towards the Earth, but is the moon part of our explanation. Were we looking at the moon |
phases to try to figure out why some places are hotter than others? No. That would be indirect light beams. So, do you want to answer that? I still wanna know why do some places up here get lower intensity light. The light is not hitting it perpendicularly, whereas this gets light coming at a perpendicular angle.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2Gary</td>
<td>Well, the Earth is on a tilt and it always rotates.</td>
</tr>
<tr>
<td>3Mrs. L</td>
<td>Does this Earth-is this Earth tilted? Do I have to tilt this Earth to make that happen?</td>
</tr>
<tr>
<td>4Gary</td>
<td>No, not really.</td>
</tr>
<tr>
<td>5Mrs. L</td>
<td>So, do-have we mentioned tilt at all yet?</td>
</tr>
<tr>
<td>6Students</td>
<td>No</td>
</tr>
<tr>
<td>7Mrs. L</td>
<td>Do you have to have tilt for that pattern to occur? So what is it about Earth that makes the light hit it at a perpendicular angle—a 90-degree angle here, but when it hits up here, it’s more spread out. What is it about Earth that makes that happen and you don’t have to have tilt for it.</td>
</tr>
<tr>
<td>8Violet</td>
<td>Because even though it’s round, it’s kind of squished in the middle.</td>
</tr>
<tr>
<td>9Mrs. L</td>
<td>Does something have to be squished for that to happen?</td>
</tr>
<tr>
<td>10Violet</td>
<td>No, but it’s in a spherical shape.</td>
</tr>
<tr>
<td>11Mrs. L</td>
<td>Oh. So the Earth is round. If the Earth were a big… if this were Earth, yeah… if Earth were this shape, if his were the equator and this were Oslo, would the light hit these two latitudes any differently?</td>
</tr>
<tr>
<td>12Class</td>
<td>No</td>
</tr>
<tr>
<td>13Mrs. L</td>
<td>Do you guys understand where I’m going with this?</td>
</tr>
</tbody>
</table>

**Episode 4**

Gary provided the first claim in line 2, bringing up the idea of tilt and rotation, information that likely came from everyday knowledge; however, Gary did not justify his idea about why these claims could answer the question. Mrs. L noticed this, and in line 3, she referred to the earth representation they were currently examining. She asked Gary if tilting the earth model she was holding
would produce the same results they were seeing with the temperature data, to which he responded, “No, not really” (line 4). Throughout the unit, students had been eager to explain the phenomenon of seasons with “tilt,” but they were unable to fully explain what this meant or how they knew it to be true, and in lines 3 and 7, Mrs. L was attempting to make that clearer to the students. By doing this, Mrs. L was trying to shift the culture from using one word answers as explanations to relying on data and observations to support claims.

Still in line 7, Mrs. L pointed the students to more carefully observe the Earth model in her hands and to make a connection between the data, the angle of the light, and the shape of the earth. Violet provided a new explanation and reasoning in line 8 when she pointed out the round, but squished shape of the earth as a way to answer the phenomenon of varying temperatures. Her source of evidence came from a general observation linked to temperature data, but rather than fully explain her reasoning, she only identified the relevant information: the round, slightly squished shape of the earth. We consider this to be very low level reasoning about evidence, and the teacher was not satisfied with this answer. She prodded Violet to expound on the importance of the “squished” aspect of the earth in line 9, to which Violet replied that the curvature of the earth is what is key to explaining the phenomenon (line 10). Using the model in her hands and another flat object from the classroom, she demonstrated how the angles of light on each shape would produce different results (line 11).
Although this episode is instrumental in demonstrating how Mrs. L challenged students to justify ideas and rely on evidence rather than commonly used terms, in line 13, she acted as the sensemaking conductor (Episode 4). When she asked the students, “Do you see where I’m going with this?” it reinforced her as an authority and removed the sensemaking and epistemic agency from students. Despite this display of traditional classroom power arrangements, the next few examples will not only exhibit the students’ unprompted attention to justification, but they will also present students’ push for greater epistemic agency. I will discuss this at length later.

As Mrs. L and the students were working together to construct an initial explanation, one student brings up the idea of including evidence to make their explanation more credible.

| 1Mrs. L | “Light from the sun strikes the Earth at different angles depending on latitude.” Does that statement make sense? Okay. Do we need a for example or is that completely clear? Do we need to clarify or does that statement make sense? |
| 2Howard | Well, maybe we should include our test results or some evidence- |
| 3Mrs. L | Evidence. Because what’s the point of evidence-what good is evidence? What’s the point of evidence? |
| 4Howard | If we don’t have any evidence how is someone gonna know that they can rely on this information? |
| 5Mrs. L | Oh. because we’re trying to like convince ourselves, teach younger people, or prove to a university professor that we understand, but we need, regardless who our audience is, we need to make sure we have evidence so we’re convincing. |
| 6Pandora | We need to have evidence to support our claim. |

Episode 5
In episode 5, which closely follows the exchange from episode 2, the teacher had just finished writing a statement on the board to include in the consensus explanation and asked if the wording of the explanation makes sense to the students and to their prospective audience. In line 1, Mrs. L specifically asked if the explanation would be clear to someone else reading it, and it is obvious she was looking for input from the students regarding phrasing or terminology. Howard had other ideas, and in lines 2 and 4, suggested that they include data from their activities to make the explanation more believable to their audience. Not only was he attending to the needs of the audience, but he was also prioritizing data as a means to convince. In line 5, Mrs. L agreed with him, indicating that of the variety of audiences the students mentioned, all would benefit from seeing evidence in the explanation. Furthermore, in line 6, Pandora emphasized that including evidence was essential to supporting their claim. This particular episode is a prime example of the foregrounded role of justification in Mrs. L’s classroom; including the source of evidence and reasoning about that evidence was important to students not only as they figure out how and why seasons happen, but also as they considered how best to share this information with diverse audiences. Although the analysis of episode 4 indicates that students may struggle with complex reasoning about sources on their own, Mrs. L still valued using evidence in the classroom to make sense of ideas. Furthermore, these two episodes together suggest that students were buying into the need to justify ideas, even if that justification was more reflective of the lower anchor of the progression (Episodes 4, 5).
While many students may struggle with sophisticated justification across an entire unit, complex reasoning is not only possible, but also present in this particular classroom. As an individual, in episode 6, Freya was capable of high level reasoning, which is an example of the level 4 reasoning highlighted in Figure 2.

<table>
<thead>
<tr>
<th>Freya</th>
<th>I was gonna say like when we did the board experiment with the graph paper. When we had it-when we had it-when we had the board pointing straight up and we had the flashlight- It had a small focused beam of light, which would kind of be like how the sun shines on the equator. And then when we tilted the board back, the light intensity become more spread out. So there would be like, a less focused point of light there.</th>
</tr>
</thead>
</table>

**Episode 6**

Upon Howard’s suggestion to include evidence in their consensus explanation, Mrs. L asked for students to think first about the different experiments they had done as a class throughout the unit. Freya responded and not only provided a source of evidence, but also did complex reasoning about that particular experiment. Freya provided the relevant information (“the board experiment with the graph paper”), and continued on, unprompted, to provide simple reasoning about the experiment (“when we had the board pointing straight up…. [the flashlight] had a small focused beam of light there”). Furthermore, she related that information back to the larger phenomenon (“which would kind of be how the sun shines on the equator”), which indicated more complex chaining of ideas. Freya’s utterance here suggests that while it may be infrequent, sophisticated attendance to justification at the individual level is indeed possible.
At the end of the three class days discussed here, the students completed their consensus explanation, which I share in episode 7. Within this explanation, the students mentioned another source of evidence (the Chinese Lantern activity) and included reasoning about the data from it.

<table>
<thead>
<tr>
<th>Class Consensus Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Since the Earth is round, the light from the sun strikes the Earth at different angles depending on latitude. When the sun's at its highest point in the sky, it's directly overhead of the Equator, and it's lower in the sky as you move toward the poles. The angle that the light hits the Earth affects light intensity. The farther from the Equator, the less intense, and hence more spread out the light it. For example, when we shone light on a Chinese lantern, we saw that the light intensity at the equator of the lantern was greatest, and it decreased as we went toward the poles. We know the light heats the ground and the ground heats the air, so the more intense the light the hotter the ground and air will be. So, this is why temperature varies with latitude.</td>
</tr>
</tbody>
</table>

**Episode 7**

This is another example of complex reasoning, and in this case, it came as a result of student collaboration rather than individual explanation. Together, the examples provided in this section suggest that justification of ideas was valued by Mrs. L, which in turn led to student buy-in. Furthermore, not only were students capable of complex justification as a group, but some students were able to accomplish this with little scaffolding. Overall, the prioritization of justification in Earth Science 2 suggests that the students and teacher co-constructed meaning that reflected authentic engagement in practices.

*Nature of account (mechanistic unpacking): Mrs. L and the students determine the account of the knowledge product.* Drawing upon one aspect of the epistemic consideration of nature of account, in this section, I examine who in
the classroom was doing the mechanistic reasoning when unpacking a phenomenon. I am specifically interested in the mechanistic load rather than the sophistication of the account, which is a different take on the epistemic consideration, but one that better serves the complex and fragmented nature of the accounts addressed across a unit. Throughout the Earth Science 2 unit, the students and Mrs. L equally shared the effort in terms of naming components of a phenomenon and reasoning about the connections among components (Figure 2). In traditional classrooms, the teacher generally carries the mechanistic load, explaining phenomena to students. What I found in this unit was that the students were capable of providing explanatory accounts of phenomena on their own, and that Mrs. L and the students were engaged in an environment that fostered this division of mechanistic labor.

In some ways, Mrs. L controlled the mechanistic reasoning in the classroom. Episode 4, from earlier in the Audience section, is a prime example of this. Prior to the start of the episode, Scott had been providing a mechanistic account of temperature variation across latitudes, but had included the term “indirect sunlight” in his explanation. At this, Mrs. L jumped in and began assessing Scott’s meaning behind this term, ultimately redirecting the conversation away from Scott’s explanation and toward gaps in their understanding. In line 1, Mrs. L finished clarifying the terminology and reframing the activity, and then redirected the students to provide a new explanatory mechanism. Gary entered in line 2 with a vague claim, but Mrs. L pointed out the holes in his response and continued to push the students to come to the
agreement that earth’s shape impacts temperature. This example shows that although there is prioritization of both justification and audience, the teacher was still acting as the mechanistic authority by driving the explanatory account.

This is not to say that the students had no purchase in explaining or attempting to explain phenomena; the students took on about half of the mechanistic load throughout the unit. For example, in episode 8, Freya attempted to explain differences in temperature through cloud cover across seasons.

<table>
<thead>
<tr>
<th>Line</th>
<th>Dialogue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Freya: I was going to say, like, it has to do with like the earth’s tilt and the seasons because, um, in the in the seasons, if you talk about cloud cover, and how sometimes the [INAUDIBLE] is covered by it-by clouds</td>
</tr>
<tr>
<td>2</td>
<td>Mrs. L: Is it just cloud cover that could explain?</td>
</tr>
<tr>
<td>3</td>
<td>Freya: No</td>
</tr>
<tr>
<td>4</td>
<td>Mrs. L: So, does that mean, like, oh when it's really cold here, in Ushuaia, it's just cloudy for months, and months, and months, and months, and months.</td>
</tr>
<tr>
<td>5</td>
<td>Freya: I think it has something to do with seasons.</td>
</tr>
<tr>
<td>6</td>
<td>Mrs. L: It has to do with seasons.</td>
</tr>
</tbody>
</table>

Episode 8

Although this was not an accurate account of seasonal variation in temperature, Freya’s mechanistic account suggests she was invested in the explanation of the phenomenon. Furthermore, when Mrs. L pushed back against her account, Freya attempted to reconcile a new account in line 5. This suggests that the meaning being co-constructed in the classroom allowed for explanatory thinking that was directed at least in part by the students.
Another student in episode 9 takes on the mechanistic load as she attends to justification in the construction of the consensus explanation.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1Red</strong></td>
<td>Um, the evidence we have on there is not completely connected to the first statement. So-</td>
</tr>
<tr>
<td><strong>2Mrs. L</strong></td>
<td>Like you want to include it later? You want-</td>
</tr>
<tr>
<td><strong>3Red</strong></td>
<td>Yeah, I think include something later to, uh- ‘cause, uh, right now we’re talking with-where it is now we’re talking about the angle of light that strikes the Earth and then after we have the evidence for that we can move onto the-how the different angles that the light striking the Earth affect the light intensity. We can move onto that after we’ve covered wha, um, after we’ve proven that it strikes the Earth at different angles.</td>
</tr>
<tr>
<td><strong>4Mrs. L</strong></td>
<td>Okay, so maybe you want to say this first, this first sentence and we’ll keep this for later. And, what would you say now instead?</td>
</tr>
<tr>
<td><strong>5Red</strong></td>
<td>Um, I would say if, um, depending on what latitude you’re standing at… if you stand at the equator at noon, um, the sun is directly overhead, but as you move north at noon, the sun is more towards the south and as you go south the sun is more towards the north showing that at, um, showing that the light will-the light is striking each latitude at a different angle.</td>
</tr>
</tbody>
</table>

**Episode 9**

In line 1, Red realized that the evidence the students included in the explanation failed to serve the knowledge product as it was currently written, and in line 3, she suggested revising the order of the statements (Episode 9). In line 5, Red provided a new mechanistic account of the phenomenon that fits better with the evidence. This is not only an exhibit of student attendance to justification, but also to mechanistic reasoning and epistemic agency, as Red felt comfortable enough to point out the errors in the original statements and construct new mechanistic accounts to replace them.
Finally, in considering the resulting consensus explanation (Episode 7), we see that students are quite capable of becoming active participants in mechanistic reasoning. As iterated in episode 2, line 3, Mrs. L directed the students to explain to her rather than just tell her what to write or wait for her input. As a group, the students were able to work together to connect evidence to a mechanistic account as they attended to audience and purpose of the explanation. Although the teacher was responsible for about half of the mechanistic work in this unit, overall, the students attended to mechanism in ways that leveraged other aspects of meaningful engagement such as attendance to other epistemic considerations and epistemic agency. Together, this indicates that Mrs. L and the students were engaged in the co-construction of meaning that prioritized student mechanistic authority.

**Student agency.** Together with attendance to the epistemic considerations, student agency makes up the meaning that the teacher and students are co-constructing in the classroom (Figure 2). Throughout this unit, the teacher and the students were negotiating agentive roles in the classroom; in some ways, Mrs. L provided opportunities for students to exercise epistemic agency, and in some ways, Mrs. L managed these moments as the authority. Overall, there was a balance between teacher- and student-led attendance to epistemic considerations, as well as a push for balance between student and teacher ownership of ideas. In this section, I highlight several examples that demonstrate student agency through asking questions, contributing ideas, and buy-in with regard to epistemic thinking.
The first example of student agency brings us back to Freya’s attendance to justification as Mrs. L and the students were engaged in a discussion about the evidence they had collected over the course of the unit.

<table>
<thead>
<tr>
<th>1Pandora</th>
<th>We need to have evidence to support our claim.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Mrs. L</td>
<td>Ah, okay. So, can we give some evidence here to like explain what this means? We did a lot of experiments. We have some evidence based on our observations.</td>
</tr>
<tr>
<td>3Freya</td>
<td>I was gonna say like when we did the board experiment with the graph paper. When we had it-when we had it-when we had the board pointing straight up and we had the flashlight- It had a small focused beam of light, which would kind of be like how the sun shines on the equator. And then when we tilted the board back, the light intensity become more spread out. So there would be like, a less focused point of light there.</td>
</tr>
</tbody>
</table>

**Episode 10**

Freya’s utterance in episode 10 comes at the tail end of Howard’s suggestion to include evidence in the consensus explanation. Howard’s initial idea was indeed an example of student buy-in to the epistemic considerations, but it was Freya’s unpacking of the evidence that shows us exactly how complex students can be. After Howard suggested the addition of evidence to bolster the explanation and Pandora’s assertion in line 1, “We need to have evidence to support our claim,” Mrs. L pointed out that the students did numerous experiments and observations so far (line 2). When she did this, Mrs. L was not directly asking students to name or explain the experiments they did as a class, nor was she explicitly reminding the students of specific activities; she was merely pointing out that they had collected a lot of data thus far in class. Freya immediately could identify one such experiment and provide sophisticated reasoning about how that experiment supported the credibility of the claims in the consensus explanation. Not only was
Freya foregrounding evidence without specific prompting, she was also unpacking that evidence and making connections, thus indicating student buy-in to the epistemic consideration of justification.

In episodes 11 and 12, Violet and Elliot were asking questions and making observations in the classroom.

<table>
<thead>
<tr>
<th>Violet</th>
<th>In Asia there’s this one spot that's always colder than the rest. Is that Mount Everest?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Episode 11</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elliot</th>
<th>Um, I was wondering why the southern pole weren't, like, got colder than the northern pole?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Episode 12</td>
<td></td>
</tr>
</tbody>
</table>

While in some cases, this would be normal student behavior, what makes these particular episodes unique is that they were unprompted by the teacher. During a segment in which a teacher asks students to make observations and connections based on data, we might expect for students to bring up ideas such as those uttered by Violet and Elliot; however, in making these observations, Violet and Elliot were actively changing the direction of the respective conversations. The class had been looking at a visualization of temperature on a map and Mrs. L asked students if the hottest temperatures occurred on land or on water. Another student provided an answer, and then Violet raised her hand to point out the very cold spot she saw in Asia (Episode 11) and asked if this could be Mount Everest. This episode indicates that Violet was buying into asking questions and constructing explanations, and that furthermore she can do so unprompted, thus exemplifying her agentive voice.
In episode 12, Mrs. L had been previously explaining that some people were visual learners and that the class should move forward to graphing the data to make sense of it. Elliot then raised his hand and asked his question about the temperature differences in the north and south poles, which indicates that he was buying into the need to ask questions and that data might raise more questions than they answer. Although Mrs. L responded by providing the mechanism to explain Elliot’s question and thereby remove a student sensemaking opportunity, Elliot’s active agentive voice in raising the question suggests that students in Mrs. L’s class found value in epistemic thinking.

**Meaning applied to final models.** After examining how Mrs. L and the students co-constructed meaning in the classroom, I now move to discussing how students applied that meaning as they were developing their final models for the unit. Based on the attendance to the epistemic considerations and the students’ tendency to exercise their epistemic agency, the co-constructed meaning from the classroom discourse indicated authentic engagement in the practices (Figure 2). By studying how students applied that meaning to their final models, we can better understand how the teacher supported students across the entire unit.

At the end of the unit, students constructed diagrammatic models to explain how and why seasons happen. This assignment was designed as part of the curriculum, but Mrs. L made a few changes to her approach. Because the students were struggling with the concept of tilt and how it affected seasonal variation in temperature, Mrs. L had the students construct 3-dimensional models
of earth's seasonal orbit around the sun. Then, in accordance with the original curricular plan, Mrs. L had students follow up to that activity by sketching their models and explaining them on paper. She also loosely framed this as a way for students to gather their thoughts as they prepared for the final unit test.

After spending the Earth Science 2 unit co-constructing meaning that valued epistemic considerations as well as student agency, the students were then tasked with applying this co-constructed meaning as they planned and created their final diagrammatic models. Based on the students’ ideas about their models in post-unit reflective interviews, we found that students applied similar meaning to their final models; thus, students prioritized and attended to the epistemic considerations in ways that matched what we had seen in the classroom data.

Epistemic considerations. In this section, I follow students’ ideas about their models and the kinds of attendance they exhibited when thinking about the construction and potential uses of their models. The patterns in attendance and sophistication of epistemic considerations matches closely the patterns found in the classroom discourse.

Audience: My model is for informing and sensemaking. Recall that in the classroom discourse, the teacher and the students frequently focused on the purpose of knowledge products in the classroom as being to inform others or make sense of ideas (Figure 2). In the interview data, we see this pattern repeated (Figures 2, 3). When students were asked “What was the goal of your model?” most students reported “to inform.” The second most common response
was to use their models to make sense of the phenomenon, either as an individual or as a class. For instance, in her interview, Violet said, “I think the goal was to really show how tilt had to do with the seasons and how the sun rays affected that.” Here, she reported that her intent for making the model was to demonstrate the link among tilt, sunlight, and seasons. In terms of using the model to make sense of the phenomenon, Frederick said his goal was “just kind of to ... bring together all the information we learned ... throughout our unit to like figure out how and why the seasons were different because I mean ... we were learning about all these different factors and just kinda to put pieces together - we've done multiple explanations beforehand so then to kinda get a like final visual representation.” Here, he referred to his classroom experience in which he perceived the events as sensemaking activities; Frederick believed this final model was the culmination of the 'figuring out' the students did in class.
Figure 3. Students’ Earth Science 2 interview responses reflecting attendance to why in the audience epistemic consideration. Students were asked to discuss the purpose of their models. Some students responded with answers in more than one coding category; all of these responses are reflected in the figure. (n=18)

The fact that students most commonly cited goals of informing or making sense with their models indicates that they likely drew upon the classroom co-constructed meaning, which also reflected prioritization of these goals during the construction of knowledge products. Although we consider the goal of informing or demonstrating to be less sophisticated than the goals of persuasion or sensemaking, I consider it a positive sign that the students are taking in and using the framing from the classroom experience. Later, in Chapter 6 I will argue that personal buy-in to the task such as the need to figure things out, as well as
more sophisticated goals of persuasion or sensemaking might result in more authentic engagement in the practice.

Not only did students have a purpose for the model, a *why*, they also had an intended audience, or a *who*. In the Earth Science 2 unit, students had a wide range of ideas regarding the audience for their final seasons model. I represent the full range of categories in Figure 4, and have indicated the most common student responses by shading the categories with the highest frequency. Student names are linked to the categories they indicated in their interviews, and in some cases, students indicated more than one possible audience category. These responses are represented with lines that converge at the student’s name. For example, as Frederick responded to interview questions regarding the goal of his model and the intended audience, he indicated that his model was constructed mainly for himself, but that anyone could use it (Figure 4). For the most part, students indicated that audiences closely connected to their school experience would benefit the most from using their model. These categories include the class, the teacher, a younger student, and themselves. This connection to school experiences might suggest that students are buying into the usefulness of models to convey ideas and make sense of puzzling phenomenon as part of the common culture of a science classroom.
Figure 4. Student ideas about who could use their Earth Science 2 model. Circles represent the various coding categories and the lines from student names to the circles indicate a student response that fits the category. The most commonly cited sources are shaded. Some students responded more than once; these responses are indicated with lines that converge at the student’s name.

Furthermore, the connection between students’ ideas about who their model was for and why that audience might use the model suggests that students were not only buying into this kind of epistemic thinking, but also that they were capable of attending to audience at a sophisticated level outside of the collective classroom thinking. While all students found value in using their models to inform a variety of audiences, eleven of the students saw their model as being able to make sense with or persuade themselves, anyone, or the class (Figure 5). For example, along with using his model to make sense of the phenomenon as a class and as an individual, Frederick saw his model as being useful for convincing someone in his class—or anyone—that this is how and why seasons happen. In his interview, he said another goal of his model could be “to help
show someone -because they can have like a theory on what happens and then maybe I could help: by using this I could show a more convincing argument. This is what happens.” In this example, Frederick was considering the goal and audience of his knowledge product in sophisticated ways, suggesting that students were capable of complex attendance to the epistemic consideration of audience.

Figure 5. Most commonly cited coding categories for who students perceived their audience to be along with the purpose of the model for that specific audience in the Earth Science 2 unit. Who categories are listed in no particular order; Why categories are listed in order of increasing sophistication along the arrow from left to right. Line thickness represents more commonly occurring links between who and why. Numbers indicate the exact frequency of these particular pairings.

Justification: I use data and authoritative sources to justify the ideas in my model. In the classroom discourse, justification of ideas was prioritized, and a special emphasis was placed on empirical data as a valid source of justification; in the Earth Science 2 interviews, there was a similar trend (Figure 2). Overall, as students discussed their models, they tended to favor empirical data as well as
authoritative sources, and when they used data as a source, the students tended to provide more sophisticated reasoning to justify their claims. In the interviews, we asked students, “What evidence did you use to support your model?” and followed that question up with, “What evidence was the most convincing to you?” As seen in Figure 6, almost all the students cited both an authoritative source and empirical data as evidence they used to support their models.

![Figure 6](image)

*Figure 6. Sources of evidence cited by students in reflective interviews in the Earth Science 2 unit. Some students responded with more than one category, and thus were counted twice. (n=18)*

When students responded to either the first question or the follow-up question regarding evidence, they also attended to the second aspect of justification: reasoning about the source. I represent these links in Figure 7. When students cited an authoritative source, they tended to engage in low-level reasoning about that source; however, when they cited data as their source,
students were capable of much more sophisticated reasoning. For example, after Kelly was asked a follow-up question about her evidence, she only gave low-level reasoning about the authoritative sources she cited (Episode 13). Similarly, after asking Violet how she knew her model to be true, she responded by citing events in class that helped her learn what was actually happening (Episode 14).

![Figure 7](image)

*Figure 7.* Links between codes for source of evidence and codes for justification about that source in student interviews in the Earth Science 2 unit. Source circles represent coding categories and are listed in no particular order. Reasoning circles represent coding categories and are listed in order of increasing sophistication from left to right along the arrow. Line thickness and numerical values represent the frequency of links between particular sources and reasoning categories in student interviews.

<table>
<thead>
<tr>
<th>Interviewer</th>
<th>Did you have any data to prove it?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelly</td>
<td>Kind of, we made a lot of explanations and we did a few models and I guess you could call them labs like the hula hoop model we made was kind of a lab so and we look at a lot of different resources so I guess you could say that.</td>
</tr>
</tbody>
</table>

Episode 13
Violet

Well, I think it’s because after we kind of talked about it and learned more about it in class, then I had a better understanding of what it should look like instead of what it might look like.

Episode 14

Conversely, when students cited data, their reasoning generally ranged from being able to identify relevant information (Episode 15), to providing a simple interpretation of the source (Episode 16), to providing a multiple source interpretation (Episode 17). In episode 15, Sam cited data the students had encountered in class. He discussed one particular activity in which the students analyzed temperature data from cities at a variety of latitudes and he pointed out some specific examples that stood out to him as he and the other students were figuring out what the data meant. Rather than explicate the link between temperature, light intensity, and latitude, Sam only provided a tenuous connection, instead identifying the data that helped him make his claim, which is an example of level 1 reasoning.

Sam

The evidence was when we were learning about the latitude and stuff, the latitude was- like in the north pole, the light would be less intense than it was at the very equator. Because of the temperatures that we had in the IQWST book, in Singapore, it was 80 degrees all year round, but then up in Belem it was, it would go down to 20 something degrees in the winter months, but then it would go up to 60 something in summer.

Episode 15

In episode 16, Percy was able to provide a simple interpretation of one particular experiment, thus reasoning at a slightly more sophisticated level than Sam. Although some of Percy’s reasoning has been prompted, he was able to indicate not only the relevant information from the classroom activity with the paper and flashlight, but he was also able to interpret how that information
relates to the phenomenon of angle of light, light intensity, and temperature. As is evident in Figure 7, most students who cited empirical evidence reasoned at this level.

<table>
<thead>
<tr>
<th>Interviewer</th>
<th>And like what piece of evidence was the most convincing for you?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percy</td>
<td>Umm, probably the tilt of the earth and the shadows...So I could see their shadows and light intensity shows- like the light is more intense- like when it's more concentrated and all that</td>
</tr>
<tr>
<td>Interviewer</td>
<td>Ok. And where did you get this evidence?</td>
</tr>
<tr>
<td>Percy</td>
<td>From like- Well we did an experiment in the science class where we took a piece of paper and we took a flashlight and shine it on the paper, so at one point we had it on 90 degrees and one point we had it like down here and every time it creates a circle, every time the angle got smaller, the light spread out more</td>
</tr>
</tbody>
</table>

Episode 16

Interestingly, at least two students were able to provide a multiple source interpretation of the evidence they cited. This higher-level reasoning includes both when a student uses multiple sources to confirm the same claim, as well as when a student uses multiple sources to interpret various aspects of a claim. Leanne’s response in episode 17 drew from a variety of activities she recalled from class and she interpreted how those contributed to her understanding of seasons. She first pointed out the activity in which the students were examining temperature at various latitudes, which showed her how the angle of the sunlight is not direct at all latitudes. Next, she cited the Chinese lantern activity in which students collected and analyzed data using a Chinese lantern as a stand-in for the earth and measured the light intensity at different latitudes, which she claimed helped her learn that “[the intensity] was different” across the earth.
Finally, she drew upon the same paper and flashlight activity cited by Percy (Episode 16) which helped her realize the connection between angle of sunlight and intensity of sunlight. Together, Leanne stated that these activities helped her realize the need to modify her model in response to new data. Not only is this evidence of higher-level reasoning as Leanne justifies her model, but it is also very telling of the meaningful way in which Leanne revised her model to fit contentious data.

<table>
<thead>
<tr>
<th>Leanne</th>
<th>Well I think that it changes because, when we were looking at um, I know when we were looking at the light intensity, and um, how the temperature like varies from, the farther you are away from the equator. Um, at first, you know I thought the light, that the light from the sun might've hit the Earth as directly everywhere. But then that wouldn't have made sense for what we were learning about like, how it got colder away from-farther away from the equator. And then as we did like um, as we did the experiment with the Chinese lantern and the different latitudes with the light sensor, um, I realized that it was different, and then also, with the evidence from, the evidence to show that it, that the light got more spread out with the graph paper that we did, where we would draw, where the light was hitting the paper, that showed me that it does get more indirect, and that it does change. And so I had to change my model so that it would fit that.</th>
</tr>
</thead>
</table>

Episode 17

In the classroom data, students were able to reason at the most sophisticated level, and demonstrated this ability on more than one occasion. While Leanne’s example was more sophisticated, it was not the norm across the students interviewed. Regardless, the ability of students to reason at higher levels when citing empirical evidence suggests that students were applying the classroom co-constructed prioritization of justification with a strong emphasis on data. We believe that perhaps one reason behind the decrease in reasoning is perhaps due to the sample of students interviewed; Freya provided an example
of level 4 reasoning in the classroom but did not participate in the interviews. Furthermore, some of the most sophisticated reasoning performed in the classroom was done with contributions from multiple students. This collaboration in the classroom discourse provided an opportunity for students to exercise reasoning skills as a community, and students could fill in gaps for each other. In an interview setting, students must rely on their own abilities, which might be less sophisticated than when they can support each other. Nonetheless, the emphasis on data in both the interviews and the classroom data, as well as the push to justify ideas especially when presenting empirical evidence is highly suggestive of students drawing upon the co-constructed classroom meaning as they discussed the ideas that went into the justification of their models.

*Nature of account: My model provides a complete causal account of the phenomenon.* Recall that the classroom discourse that centered on unpacking the mechanism was divided equally between Mrs. L and the students (Figure 2). Thus, as the students and Mrs. L were co-constructing meaning in the discourse, they contributed fairly equally to the mechanistic work being done. We see this co-constructed attention to mechanistic unpacking manifest in the student interviews as the students reasoned about the phenomenon of seasons with their models at relatively sophisticated levels. This is evident in Figure 8, as most students were able to name both factors and unpack at least one of those factors while discussing their models.
Figure 8. Causal accounts of the phenomenon provided by students in their final models in the Earth Science 2 unit. Circles represent coding categories and are listed from left to right in order of increasing sophistication along the arrow. Lines to student names indicate students with interview responses coded in a particular category. Dotted lines indicate reasoning that occurred with incorrect accounts of the phenomenon. (n=18)

Elliot is one student who was able to reason about seasons at the most sophisticated level. In episode 18, Elliot explained his model in a way that not only named both of the factors critical to explaining seasonal variation in temperature, but also in a way that unpacked the relationship of those factors to the phenomenon.

| Elliot | I was trying to answer the question of why do seasons happen. And I think my model explained that because right here it shows in the northern hemisphere it being...I believe it's summer. And then while the southern hemisphere is being winter because the tilt is pointed toward the sun more. The northern hemisphere is pointed toward the sun because the North Star- the tilt is always pointed toward the North Star. And then this season is, for the northern hemisphere it's fall and for the southern hemisphere it's spring because it's hitting the equator and it's also still pointing at Polaris. And then the next season would be winter |
for the northern hemisphere and then for the southern hemisphere it
would be summer because the light's rays - they have the most direct
sunlight at the southern hemisphere and the least direct in the northern.
And then that would mean that the season in the northern hemisphere
would be... wait... I think it would be - wait fall- wait, let me check. This
would be spring because... Yeah, it'd be fall because... I'm getting these
mixed up. So it goes summer... yeah, it'd be spring because it's pointing
at the equator the most intense.

Episode 18

In order to be considered a complete explanatory account of seasons, students
needed to name earth’s tilt as well as sunlight angle or intensity and then reason
about how those two factors contribute to the change in seasons in each
hemisphere. Elliot did this by recognizing the fact that the earth’s tilt “is always
pointed toward the North Star,” and later introducing the idea that the sunlight
intensity contributes to warmer seasons. He unpacked the relationship between
these factors by saying that the when the Northern hemisphere is experiencing
summer, the Southern hemisphere is experiencing winter “because the tilt is
pointed toward the sun more” and that these seasons switch when earth’s
position changes and the southern hemisphere begins getting the most direct
sunlight.

Howard (episode 19) provided an example of sophisticated reasoning that
occurs after the interviewer prompted him to explain an aspect of his model.
Notice how both Howard and Elliot were capable of unpacking the nature of the
phenomenon at high levels, indicating that not only did they understand the
content presented in the unit, but that they also were able to use their models to
explain the complete causal mechanism of seasons.
Howard: Well, this is showing the tilt of earth relative to the plane of earth's orbit. And then it's kind of - it's showing why the seasons are different in the northern hemisphere because of how the angle changes and the same latitude depending on where earth is in its orbit.

Interviewer: Ok. So why did you include these little bubbles here?

Howard: Oh, to show the angle at which the light is hitting the ground in the northern hemisphere changes throughout the year, and that is - that affects it by having the light intensity be different in fall and winter because the light is less intense because it hits it at a shallower angle.

Episode 19

While most students exhibited the most complex reasoning about seasons as they discussed their models, a large portion of students reasoned at a slightly less sophisticated level; Violet was one such student (Episode 20). Although she mentioned both earth's tilt and the angle of sunlight, she only unpacked the effects of tilt and omitted reasoning about the intensity of light. Regardless, Violet’s attendance to the nature of account here indicates a sophisticated handle on both the content and her model's ability to represent the phenomenon.

Violet: We learned that tilt- that the tilt never changes. It just doesn't, like, go that whole way, it's always pointed toward Polaris which is the North Star... And so at the different places, like the northern hemisphere when it's summer, it's actually closest to the sun, but it's also getting more direct sunlight, so we tried to show that with the sun rays. And basically the same thing is happening to the South Pole when it's their summer and our winter. And then for fall and spring, since the earth isn't either closer or farther from the sun, it's getting the same light, so that's why the temps are varying the same.

Episode 20

Similar to the co-constructed meaning from the classroom discourse, students were bringing higher level attendance to nature of account into their
final models in the Earth Science 2 unit. Based on the classroom data, the teacher spent more time engaging in mechanistic reasoning with the students and the students also took charge in about half the of the mechanistic work seen in the discourse. Very little time in the classroom was spent engaged in low-level interactions, and together, these findings suggest that the discourse led to co-construction of meaning that prioritized students’ abilities to reason about a phenomenon using a model. The students’ responses in the interviews about their final models indicate that students bought into the co-constructed meaning. Because the students tended to provide more sophisticated accounts of the phenomenon as they discussed their model, we believe that students have included both content knowledge and mechanistic reasoning to their model as applied aspects of the co-constructed classroom meaning.

**Summary of findings from Earth Science 2**

In short, the data across the classroom discourse and the student interviews suggest that Mrs. L supported the students in meaningful engagement in modeling across the entire Earth Science 2 unit. As she worked with the students in the classroom, Mrs. L cultivated an environment that promoted epistemic thinking, specifically in terms of attendance to audience and justification, and in turn, the students pushed for stronger agentive voice as they initiated attendance to epistemic considerations. This co-constructed meaning prioritized epistemological aspects of scientific practices in way that was both authentic to the discipline and also important to the students. We see that students applied this meaning to their final models, which further supports
student buy-in. Finally, because these trends in sophisticated attendance to epistemic considerations and student agency were co-constructed in the classroom and then applied by the students in their final models, it indicates that Mrs. L supported the students in meaningful modeling across the entire unit.
Chapter 4: Biology 2

In Chapter 4, I analyze the second case from my larger multiple case study as a means to figure out how a teacher supports students across several modeling units. Again, I examine both classroom co-constructed meaning that emerges as a result of the discourse between Mrs. L and her students over the course of the unit while engaged in scientific practices and then I compare that to the meaning students applied to their final models. What I present in this chapter stands as a contrast to the story from Chapter 3 in which Mrs. L supported students in meaningful practice engagement across the entire unit; here, we fail to see evidence that students were engaged in meaningful modeling as they reflected upon their final unit models. In the Biology 2 unit, Mrs. L supported students in the classroom as they co-constructed epistemic meaning, but did not sustain this support to the construction of the final model (Figure 9). Below I share a brief outline of how patterns in attendance to the epistemic considerations and negotiation of student epistemic agency contributed to our understanding of meaningfulness in the Biology 2 unit.

- **Audience. Who will use our model and how?** Mrs. L and the students attended to audience in the classroom in ways that heavily prioritized the goal of informing, followed by using knowledge products to make sense and clarify ideas. This co-constructed
prioritization of sophisticated audience purposes was not maintained by students as they discussed their final models. In reflective interviews, students focused on using their infographics to inform.

- **Justification. How do we justify the ideas in our model?** In the classroom discourse, data was prioritized by Mrs. L and the students as a salient source of evidence, and students tended to reason at level 2, although level 0 and 3 responses were also present. In the reflective interviews, students generally failed to cite evidence, and when they did, they failed to reason about it beyond a level 0.

- **Nature of account. What kind of answer should our model provide?** Mechanistic reasoning was heavily prioritized by Mrs. L and the students as they were co-constructing meaning in the classroom discourse. Both parties shared in the unpacking of phenomenological accounts relatively equally. This co-constructed attendance to nature of account was not applied as students discussed their final infographics, as only half of the students were able to unpack a partial mechanistic account.

- **Student Agency.** In examining how Mrs. L and the students negotiated authority in the classroom discourse, the students tended to push for more voice in data collection and analysis, raised questions, and responded to peers more frequently.
Figure 9. Classroom co-constructed meaning, the teacher approach to the final models (an infographic), and how the students applied meaning to their final models in the Biology 2 unit.

Figure 9 depicts the trends in classroom co-constructed meaningfulness and applied meaning. Similar to the audience trends in the Earth Science 2 unit, Mrs. L and the students attended to the goals of Inform and Sensemake, but also considered the ability of the classroom knowledge products to Clarify (emphasizing aspects of the knowledge product meant to more clearly convey ideas). In terms of justification, the classroom community continued to value Data as a source of evidence, but more frequently reasoned at a level 0 (the claim is correct without justification). Again, both the teacher and students engaged in mechanistic unpacking (nature of account) and students exercised epistemic agency (bold border, Figure 9). The teacher approach to the final models was a stark contrast to the knowledge product construction occurring in class and in the curriculum (Double bar, Figure 9). While the meaning applied to the final models was much less sophisticated than the co-constructed meaning, it played a larger role in students’ construction of their final models, which I represent here with a larger, darkly shaded rectangle (Figure 9). A more complete version of the coding rubrics can be found in the appendix.
Overall, in this chapter, I describe the ways in which this unit was similar to the meaningfulness found in the Earth Science 2 unit and the ways in which the Biology 2 unit was starkly different, particularly in terms of the final models. I will present evidence that supports my claim that Mrs. L failed to support authentic science engagement across the entire Biology 2 unit. As I show the ways in which Mrs. L and the students attended to the epistemic considerations and negotiated epistemic agency in the classroom discourse, I argue that the co-constructed classroom meaning represents authentic engagement in the practices. As I move to the interview data and the ways in which students attended to the epistemic considerations while discussing their final models, I argue that the applied meaning is more reflective of rote participation in an activity. Although I briefly discuss possible explanations and implications of this shift in meaningfulness, I will unpack the majority of these ideas in Chapter 6.

Data Summary

To frame a more complete understanding of the unit as a whole, I begin by describing the data collection and the ways in which Mrs. L modified the unit to achieve new goals. This information is particularly critical to the analysis of the discourse and interview data, as it provides a new lens through which to view the shifts that occurred between the meaningful practice engagement seen in the classroom and the rote activity enactment seen in the reflective interviews. I first describe the design of the Biology 2 as presented in the IQWST curriculum, then I provide a brief explanation of the content of the three classroom days on which I
center my analysis, and finally I explain the ways in which Mrs. L modified the unit by adding and removing activities.

**IQWST unit design.** The Biology 2 unit was divided into three learning sets, and I collected and analyzed videos from eight classroom days throughout the unit. In the first learning set, entitled “What is inside me?,” students learned about the cell as the major unit of life; two videos from my dataset come from this grouping of lessons. The second learning set, “How do cells get the things they need?,” focused on using food to get energy; the remaining five videos from my dataset are from this learning set. Finally, the third learning set, “Movement and control,” incorporated the information from the previous learning sets and added the element of exercise to the driving question, “what is going on inside me?”; I collected no videos from this learning set, because the teacher omitted it.

Table 4

*The nature of classroom activities and attendance to Epistemic Considerations on three videotaping days in the Biology 2 unit.

<table>
<thead>
<tr>
<th>Epistemic Consideration</th>
<th>Lesson 4-2, Day 4</th>
<th>Lesson 5-2, Day 3</th>
<th>Lesson 5-2, Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration (Minutes)</td>
<td>Episodes</td>
<td>Duration (Minutes)</td>
</tr>
<tr>
<td>Audience</td>
<td>9</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Justification</td>
<td>2</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Nature of Account</td>
<td>11</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nature of Activities</th>
<th>Lesson 4-2, Day 4</th>
<th>Lesson 5-2, Day 3</th>
<th>Lesson 5-2, Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-Task</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Group work</td>
<td>7</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Whole-Class Discussion</td>
<td>20</td>
<td>35</td>
<td>17</td>
</tr>
</tbody>
</table>
As with the Earth Science 2 unit, I am providing a more detailed analysis of three particular classroom days from this unit to give a more cohesive and contextualized look at how the students and teacher work together to co-construct meaning in the Biology 2 classroom. In table 4 I share the length and brief content descriptions of the focus videos, which all come from the second learning set. I will be describing these videos in depth below, and then describing the ways in which Mrs. L envisioned and enacted the unit as a whole.

**Lesson 4-2, Day 4.** Activity 2 in Lesson 4 was spread over the course of four days, during which the students spend a great deal of time modeling digestion and critiquing each other's models. The first five minutes of this class was spent with students wrapping up their models of how the stomach is involved in digestion and sharing them with a partner. Next, the teacher transitioned to having students share their models with the class by reminding students of the overall goal of this modeling practice: to produce an infographic to share with others at science night. Mrs. L spent time discussing this goal with the students, getting them excited, and warning them about procrastination. The task framing that Mrs. L did here provides some insight to ways in which she might have framed other activities throughout the unit, and I will spend some time discussing this later.

Next, Mrs. L asked the class to nominate a few student models to share with everyone, “Can somebody nominate one that they saw that they thought
was doing a very good job of displaying why and how so we can take a look at it?” Mrs. L spent a great deal of time throughout the course of this lesson to focus on “why and how” – the mechanistic components of the model – as students engaged in the practice. In response to Mrs. L’s call for effective models, Violet and Elliot shared their models and their classmates provided some in-depth comments and critiques of their respective models. Although she encouraged the class to offer suggestions to Violet and Elliot, Mrs. L seasoned the commentary with guidance and a strong focus on mechanistic thinking. In this final installment of Lesson 4-2, which lasted about 27 minutes, there was a strong focus on the epistemic considerations of audience and nature of account, likely due to Mrs. L’s influence as authority and her ultimate goal of an infographic.

**Lesson 5-2, Day 3.** Like Lesson 4, Lesson 5-2 was spread across several days and had a strong emphasis on modeling. The first day of lesson 5-2 started with an activity in which students observed osmosis in onion cells; during Day 3 of this lesson, the students shared their models explaining those observations. Mrs. L began by asking Freya to share the model she constructed to explain what she thought was happening to the onion cell. After Freya presented her model, Mrs. L opened up the discussion to allow the class to provide feedback regarding Freya’s model. Next, William shared his model for explaining what was happening to the onion cell, and several students offered him some comments regarding his model. Howard spoke up and said that William’s model could have been more explanatory. Mrs. L reminded the students that while they know more about osmosis now, at the time William and Freya drew their models, the class
did not really know what was happening; they were trying to make sense of their observations. This transitioned to another sensemaking activity in which Mrs. L re-created the simulation with a plastic baggie full of water.

Along with the baggie activity, Mrs. L brought up the other activities from this lesson, such as the egg placed in vinegar, and together the class worked to make sense of what was happening during osmosis. This discussion comprises the remainder of the classroom video. While much of the video is dominated by teacher-led sensemaking, the students still asked questions, considered hypothetical scenarios, and put the thinking into their own words, which I will discuss in depth in the student agency section of this chapter.

**Lesson 5-2, Day 5.** As mentioned above, Lesson 5-2 was completed over the course of five days, and I focus here on the last classroom period in this sequence. On day 3 of this lesson, the students suggested a new investigation involving the egg membrane to test their ideas about water movement. On day 5, which is where my next focus video begins, the class observed the results of that investigation and then the students suggested a next step for the investigation. After getting that set up, Mrs. L introduced the day’s activity: building another model. As she framed this task, she pointed out that students would be revising their previous osmosis models from day 3 using the new evidence they collected from the egg and baggie activities. Mrs. L also framed the target audience as the class and the purpose of the model both to convince ("...you’re gonna defend that to the rest of the class") and to show content knowledge ("We want to know that you are explaining it correctly"). Although the first goal of the model is more
sophisticated, we start to see part of the larger theme of Mrs. L's focus on correctness, which will carry into her goals for the final models.

Before students actually got started on their partner models, they spent some time as a class discussing all the evidence they had collected so far and then creating a list of ideas that represent good modeling techniques. Students explained the evidence and provided a variety of ideas for things to include in their models, and Mrs. L emphasized that although these were excellent ideas, the list was not exclusive nor mandatory, simply a guide to help students think through their mechanistic reasoning. Throughout this discussion, Mrs. L focused on getting students to explain parts of the phenomenon of osmosis as they reasoned for including a component of the model. Finally, for the last half of the class period, Freya and Red build a model together, and then Sheldon and Daisy join them for a group consensus model. Overall, this particular classroom video had a strong emphasis on the epistemic considerations of audience and providing mechanistic accounts, and a slightly lower emphasis on justification.

Teacher Approaches to the Unit. In the Biology 2 unit, Mrs. L had big ideas for the final product of the unit and changes to include aspects from other classes. Originally, Mrs. L and the other eighth grade teacher, Ms. P, reached out to us seeking ways in which they could incorporate a research study into the unit. Ideally, they had wanted to partner with a local university researcher to mentor the eighth graders and help them design and enact a study that would include input from other subjects, such as fitness and language arts. We met several times with Mrs. L and Ms. P and the university scientist, Dr. H, to draft ideas for
supporting students as they asked their own driving question, collected data in their fitness and wellness class, made sense of the data in science class, and designed an explanation in their language arts class. Mrs. L and Ms. P envisioned a final knowledge product in the form of an infographic explaining how food and exercise contributed to disease states such as diabetes or obesity (Episode 21). The goal of this infographic would be to share with students’ families and other patrons at the school’s annual science night.

Mrs. L  ...there was a board meeting last night and [Miss W] presented to the board about our project and they seemed really, really excited about it. She was telling them how wellness, and fitness, and science and stem foundations are working together to make this calendar and infographic to explain how to reduce your risk of obesity related disease. And they seemed really interested in it, and they want us to present our projects once we’re all done in a few months. And so I was really excited about that. I also want you to remember the big picture: making an infographic at the bottom of your calendar to explain how metabolism works. And many times when we do projects, the common feedback... is that you feel overwhelmed because you have too much to do and too little time. And so Ms. P and I have built in these models every step of the way so you are documenting the big ideas that you’ve learned.

Episode 21

To accommodate the teachers’ new plans for the Biology 2 unit, they decided to remove the last learning set in lieu of more time spent on the first two learning sets. Mrs. L and Ms. P planned to supplement these first two learning sets with not only the student research project, but also additional modeling activities throughout the lessons. The teachers both valued modeling, and wanted to provide students with ample opportunities for growth in modeling before the final infographic.
Despite the support provided by the researchers associated with this study as well as the expertise from Dr. H in terms of the student independent projects, Mrs. L and Ms. P ultimately abandoned the plans for the student research project very shortly after the start of this unit. Both teachers reported feeling overwhelmed by the prospect of supporting student research in an area different from their respective science backgrounds as well as by the challenges of coordinating the involvement of various subjects and other teachers. Mrs. L and Ms. P removed the student research projects from the plans and instead focused more on their final goal of the infographic. Much of their original plans remained intact; they added more modeling to learning sets 1 and 2, learning set 3 was omitted, students spent time in other classes such as fitness and language arts making connections to the Biology 2 unit and improving their written explanations, and the infographic remained an important goal for both the teachers and the students. Dr. H’s role in the unit became greatly diminished, but she still made a trip to the school for a grade-wide presentation of her research interests and a question and answer time.

Analysis of Findings

Now that I have explained the context of the Biology 2 unit, I move to exploring how Mrs. L supported these students across the unit as evident in attendance to the epistemic considerations. I start with an in-depth analysis of how Mrs. L and the students co-constructed meaning in the classroom discourse that was reflective of authentic engagement in a practice. Then, I discuss how patterns in the reflective interviews suggest that students failed to apply that co-
constructed meaning to their final models. While I save much of my discussion of the larger themes for Chapter 6, I end this chapter with a brief summary of the shifts that occurred throughout this unit.

**Classroom Co-Constructed Meaning.** With respect to epistemic consideration attendance and negotiation of student agency, the co-constructed meaning in the Biology 2 classroom aligned with aspects of both scientific authenticity and personal relevance (Figure 9). In the discourse, Mrs. L and the students worked together frequently to build knowledge, and there were multiple opportunities for students to respond to each other (with the teacher guiding), specifically in terms of modeling critique. Attention to mechanistic reasoning was prioritized in the classroom, as determined by coding averages, closely followed by attendance to audience, and then justification. Out of all three units I investigate in this dissertation, the Biology 2 unit produced the least attendance to justification in the classroom, likely because the teacher was mainly focused on students’ abilities to model the phenomenon correctly. Students had more agency in this unit than in the Earth Science 2 unit, asking questions and giving feedback to peers when the teacher provided space to do so. Below, I unpack each of these claims and reason about how they contributed to the overall co-construction of authentic meaning in the Biology 2 classroom.

**Epistemic considerations.** In thinking more specifically about the epistemic considerations, there was strong attendance to mechanism and audience by both Mrs. L and the students. Although the teacher did a fair amount of mechanistic work in this unit, the students exercised both mechanistic
reasoning and epistemic agentive voice as they constructed, shared, and critiqued models throughout the lessons. Attendance to audience was to inform, clarify, and make sense, and these themes were prevalent across the discourse. Although justification took a backseat to the other epistemic considerations in terms of time spent in explicit evidence-based talk, data was largely prioritized over other forms of evidence, which indicates that the group co-constructed meaning that valued empirical data (Figure 9). I will describe the attendance to each epistemic consideration in detail below.

**Audience:** My model is to inform and make sense. In terms of the purpose behind the models and explanations students were creating in class on the three focus days, the most common goals were to inform, either through explaining or clarifying, and to make sense as a class (Figure 9). Students rarely had explicit audiences as they were constructing their individual or partner-generated knowledge products on these days, but Mrs. L was very clear in determining an audience for the final infographic. As I have mentioned earlier and will discuss later in chapter 6, it seemed as though Mrs. L’s goals for the infographic influenced some of her discourse moves, specifically in terms of the models students constructed throughout the unit.

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<th>Mrs. L</th>
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<td>... And [the school board] seemed really interested in it, and they want us to present our projects once we're all done in a few months. And so I was really excited about that. I also want you to remember the big picture: making an infographic at the bottom of your calendar to explain how metabolism works.</td>
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<th>Mrs. L</th>
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<tr>
<td>And many times when we do projects, the common feedback... is that you feel overwhelmed because you have too much to do and too little time. And so Ms. P and I have built in these models every step</td>
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</table>
of the way so you are documenting the big ideas that you've learned. So I really want you to take these models seriously...

3Mrs. L And if you are putting very little effort into your models, you will then find that the end of the project when you have to put all this information together to explain metabolism, that's going to be very challenging for you. You're going to feel overwhelmed and you're going to feel upset because it's too much to do and too little time.

5Mrs. L So make sure you have very thorough detailed models including all that information you've learned so that when you get to the end and you're making this model of metabolism, which may or may not include the mouth, you may have to zoom out, not just zoom in on one organ at a time, but you've got all the information about what happens to food in the different parts of the body. Does that make sense?

6Mrs. L I want you to see the big picture so you understand why we're doing this. Because some people are still like, "well why do I need to draw these models?". All right.

Episode 22

On one particular day, Mrs. L reminded students about the final knowledge product and the overall goals for that product: an infographic to share at the school’s science night (Episode 22). I briefly introduced Mrs. L’s discussion of the infographics in episode 21, but here I expand further on her explanation to the students. Not only does this episode frame the audience as the school board, students’ families, and anyone else coming to the science night, but it also provides students with the “why” behind their infographics: “to explain how metabolism works.” In line 2, Mrs. L framed the goal of the additional models, such as the ones students work on later in the class period, as being part of the scaffolding to support the final infographic. She discussed these models as ways for students to “[document] the big ideas,” which we consider a more rote
approach to the purpose of modeling in terms of audience attendance.

Furthermore, in line 5, Mrs. L told the students to “make sure you have very thorough detailed models including all that information you’ve learned,” which again emphasizes the modeling activities as having the less sophisticated goal of informing rather than making sense or persuading an audience. Although we will see students identifying sensemaking as a purpose of their models in the classroom, we will also see how Mrs. L’s approach to the final model here set the stage for how she approached knowledge product generation and construction of meaning in the classroom.

In the next episode, the class was examining a student’s model and then providing feedback regarding that model. Mrs. L read Violet’s model of how and why the stomach is involved in digestion to the class and various students offer some suggestions or criticisms of Violet’s model (Episode 23). Throughout this episode, the main focus was on the mechanism behind the phenomenon: how well the model conveys “how” and “why” the stomach helps digest food. Mrs. L prompted this in line 1 and then continuously refocused students on this prompt. I will discuss more about the mechanistic focus of this episode later in this chapter; for now, it is important to notice how in line 12, Elliot began to bring up the idea of Violet’s audience.

<table>
<thead>
<tr>
<th>1Mrs. L</th>
<th>So let's read this. &quot;Bolus enters the stomach so its nutrients can be broken down.&quot; Does that tell why or how or both? What does that tell us? Sam?</th>
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<tbody>
<tr>
<td>2Sam</td>
<td>Well I think that, I think that where it shows how, like, like, how to the bolus actually gets down the system, but I don't think it really explains how it turns into chyme.</td>
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<tr>
<td>3Mrs. L</td>
<td>So if I ask you the question. Just from this statement &quot;Bolus enters the stomach so its nutrients can be broken down.&quot; I asked you why do you need a stomach.</td>
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<tr>
<td>4Sam</td>
<td>No it didn't.</td>
</tr>
<tr>
<td>5Mrs. L</td>
<td>Pandora, do you agree?</td>
</tr>
<tr>
<td>6Pandora</td>
<td>I think it's both.</td>
</tr>
<tr>
<td>7Mrs. L</td>
<td>You think it's both. What part of this is how and what part of this is why?</td>
</tr>
<tr>
<td>8Pandora</td>
<td>Because it explains the bolus goes down...it explains how the bolus gets to the stomach and it also explains why it goes into the stomach.</td>
</tr>
<tr>
<td>9Mrs. L</td>
<td>Why does it go into your stomach? Why do you need the stomach?</td>
</tr>
<tr>
<td>10Pandora</td>
<td>So it can break down your food and you can get the nutrients.</td>
</tr>
<tr>
<td>11Mrs. L</td>
<td>So you're, what I'm hearing you saying is so it can be broken down. So the nutrients can be broken down is the why. Elliot?</td>
</tr>
<tr>
<td>12Elliot</td>
<td>Um, I think this is another thing, like, where you have to have background knowledge and stuff. Because when it says it's breaking down, it's not saying the stomach's breaking down or I can't really see it that great.</td>
</tr>
<tr>
<td>13Mrs. L</td>
<td>So I'll read it again. &quot;Bolus enters the stomach so its nutrients can be broken down.&quot;</td>
</tr>
<tr>
<td>14Elliot</td>
<td>And it doesn't really explain, like, the chemical digestion and mechanical digestion</td>
</tr>
<tr>
<td>15Mrs. L</td>
<td>So it doesn't explain how it's being broken down. What we know, breaking it down is the purpose. Why do you need your stomach? To break down nutrients. Do we know yet how that's happening?</td>
</tr>
<tr>
<td>16Elliot</td>
<td>No</td>
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</table>

Episode 23
While most students in this episode were focused on following Mrs. L’s guidance and commenting on the nature of account Violet was providing in her model, Elliot broke away and pointed out how Violet’s model might have a specific audience. In line 12, he noticed that Violet failed to give a complete account of the phenomenon of stomach digestion, which meant that her model was likely only suitable for someone who has background knowledge on the subject. In line 12 and again in line 14, Elliot specified that Violet’s representation left out how the stomach is involved in breaking down food both chemically and mechanically, and he admitted that at least for him, this process was unclear based on the model. Rather than acknowledge Elliot’s shift toward focusing on audience, Mrs. L took this comment as feedback on how well Violet is representing the mechanism (Line 15). In that same line, Mrs. L further pointed out that the class did not yet know exactly how the digestion occurs, which could have been a prime opportunity for her to frame the modeling activity as one of sensemaking, but Mrs. L held to her focus on mechanism.

<table>
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<tr>
<th>17Mrs. L</th>
<th>Not yet. Freya?</th>
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<tr>
<td>18Freya</td>
<td>I'd like to point out that maybe depending on who Violet's audience would be, you would have to figure out this is for younger children, do you need that background information?</td>
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<tr>
<td>19Mrs. L</td>
<td>Right. So that's an important point. Who is the audience? What, what are we assuming this person knows at this point in this, in this model. Is this model for a sixth grader who, like, if I were a sixth grader, I'd be like &quot;bolus? What the heck is that? That sounds funny.&quot; But you guys know what a bolus is already. What do you think Kelly? Just your opinion.</td>
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Another student, Freya, latched onto Elliot’s attendance to audience, and in line 18, she expressly brought up the notion of who Violet’s audience might be. Whereas Elliot only tacitly touched on the absence of background knowledge and how that might affect the reader’s understanding, Freya was explicitly challenging the need for background knowledge, as perhaps Violet intended her audience to be more experienced. Freya’s attendance is incredibly sophisticated in this utterance, as not only was she thinking about how a viewer might perceive Violet’s model, but also, she was reflecting on the idea that Violet’s intent for the model’s audience might be different than Elliot’s, and because Violet was the modeler, the class should be considering how effectively Violet accomplished her own goals rather than how well she met Elliot’s needs.

Mrs. L again attended to the importance of considering audience as one constructs a model (Line 19), but rather than asking Violet who she made her model for, Mrs. L asked for critiques on how well Violet’s model could explain digestion to a sixth grader. This discourse move took away some of the modeler’s agency by trying to retroactively placing boundaries on the kinds of epistemic decisions Violet made as she was constructing her model, and might even have had the unintended effect of influencing the audience considerations of other students. For instance, students might have begun to construct their
knowledge products not with one singular audience in mind, but a more encompassing audience so as to appeal to the critiques of classmates and teacher. Nonetheless, despite Mrs. L’s question about how well Violet’s model could explain digestion to a sixth grader, Kelly added to the earlier conversation regarding the nature of Violet’s account (Line 20). At this, Mrs. L dropped the caveat regarding audience and returns to her main goal of guiding critique on the “how and why” of students’ digestion models.

Episode 23 represents a stark difference in student and teacher attendance to the epistemic consideration of audience. While Mrs. L focused primarily on the mechanistic account of student models, several students pushed back and entertained the consideration of audience. This attendance by Elliot and Freya indicates that students were not only capable of identifying how well a model meets the needs of a particular audience, but also that some students could consider a modeler’s intent for audience based on model content (Freya). Because Freya and Elliot attended to audience unprompted, this suggests that were buying into the need to account for audience as they engaged in a practice. Together, this means that students were actively co-constructing meaning that valued attendance to audience.

On another day as students were sharing models and providing feedback for their classmates, William shared his model of the onion experiment with the class. In Episode 24, we see Keshawn and Howard responding to Mrs. L’s focus question: Is William’s model showing how and why?
In line 1, Keshawn remarked that William’s model is showing “how” the onion cell acted when salt water was added to it, but then in line 3 distinguished between a model showing and a model explaining; in William’s case, his model was only showing. Mrs. L did not probe Keshawn further about his word choice, but it seems clear to us that students in this class saw a difference between models that show and models that explain. In the case of the former, Keshawn was indicating a lower level of sophistication: perhaps the user of the model was able to see a representation of a phenomenon, but was unable to interpret the mechanism of the phenomenon. In the case of the latter, Keshawn seemed to mean that the user was able to both see and understand the mechanistic account provided in the model. While we do not distinguish between show and explain in our coding rubric (our research indicates that students often use these terms interchangeably to indicate communication when discussing their models), this differentiation by Keshawn suggests that students in Mrs. L’s class were
capable of complex evaluation of a model’s purpose. Although Keshawn did not further expound upon his word choice here, it is clear that students were actively involved in the co-construction of meaning in terms of the epistemic consideration of audience, specifically the purpose of models.

In this same episode, we also see how the teacher contributed to the co-construction of meaning in understanding the goals of models (episode 24). In line 5, Howard commented on William’s model in a way that attended to the nature of the account of the phenomenon. Here, Howard suggested that William provide a more mechanistic account of what was happening to the onion cell. It had been several days since the students completed the onion cell activity and constructed their models, so the students now have a better understanding of what was happening to the onion cell; ergo, Howard had a higher expectation for the mechanistic representation of William’s model. Furthermore, Howard failed to see that William was likely constructing his model for the purpose of making sense of the phenomenon and Howard was instead critiquing William’s model on its ability to demonstrate or explain the phenomenon to a more advanced audience. Mrs. L noticed this in line 6, and reminded Howard of the students’ understandings of the mechanism at the time of model construction. She said that on Friday, when they were observing the onion cell and constructing the model, the students were still trying to figure out what was happening to the onion based on the changes in color as they added saltwater and freshwater to it. In doing this, Mrs. L was supporting students in the co-construction of meaning
as the class considered the connections among content knowledge, model purpose, and the timing of model construction.

In the Biology 2 unit, there were examples of both low-level and sophisticated attendance to audience as Mrs. L and her students co-constructed meaning. Although Mrs. L had identified more rote goals in terms of the audience and purpose of the final model for the unit, the students made several complex moves in the classroom that indicated a more comprehensive grasp of the epistemic consideration of audience. Even when Mrs. L framed modeling tasks with a mechanistic focus, the students pushed back and also considered the modeler’s intent in terms of who the model is for and why that audience would use the model (Episode 23). Alternatively, when Howard applied an irrelevant standard to William’s model, Mrs. L reminded him of William’s possible frame of mind as he was deciding the audience and goal of his model (Episode 24). Together, this push and pull between Mrs. L and the students indicates a heavy emphasis on audience as the class co-constructed meaning in the Biology 2 unit.

Furthermore, although there was prioritization of communication and sensemaking goals of knowledge construction in the classroom, the strong sense of teacher framing of the final knowledge product might lead to discrepancies in students’ application of meaning as they build and discuss their final models. I will tackle this interesting development later in this chapter as I discuss the interview data and then again in Chapter 6 as I discuss the major trends across units.
Justification: We justify the ideas in our model with data. As Mrs. L and the students engaged in practices in the Biology 2 classroom, they were attending to the epistemic consideration of justification by prioritizing data over other sources of evidence and doing lower-level reasoning about evidence (Figure 9). While both Mrs. L and the students brought up justification unprompted, the more complex examples of reasoning tended to occur when Mrs. L was guiding the class in a sensemaking endeavor. When students engaged in richer attendance to justification, it was generally unprompted suggestions for hypothetical evidence to support a claim, which also indicated an increased sense of student agency. The first example I highlight is a continuation of episode 24 in which Mrs. L and the class discuss their observations from the onion cell activity and provide a simple interpretation of the data.

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<td>Howard</td>
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<td>2</td>
<td>Mrs. L</td>
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<td>3</td>
<td>Lindsay</td>
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<td>4</td>
<td>Mrs. L</td>
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<td>5</td>
<td>Lindsay</td>
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<td>6</td>
<td>Mrs. L</td>
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<td>7</td>
<td>Alfred</td>
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</table>
It would shrink. So, the fact that it’s doing this implies that water is doing what? What is the water doing? In order to dehydrate what’s the water have to do? Leaving, right? And then, we see that it pumps back up, so water must be?

Getting back in.

Episode 25

Episode 25 started with Howard’s comment regarding the lack of mechanistic complexity in William’s onion cell model. In line 2, Mrs. L reminded Howard that William and the rest of the class did not fully understand what was happening to the onion as they were drawing their model – the model was for sensemaking purposes. Then, Mrs. L began to reiterate the observations from that activity and lead the students in doing some preliminary sensemaking regarding osmosis. In lines 2 and 4, Mrs. L pushed Lindsay to recount the important information from the activity; we consider this to be level 1 reasoning about the evidence. She included input from Alfred in line 7, and in line 9, Scott’s answer provided the implication behind the patterns they were seeing. Even though the students were giving the keywords in this episode, Mrs. L was making the larger connections, providing the blueprint with which students could easily make sense of the data. Again, although this was a low-level example of justification – and one directed by the teacher at that – episode 25 is an example of how data was foregrounded as a source for understanding scientific phenomenon in this unit.

Episode 26 is another example of how empirical evidence was prioritized as a means for knowing. In this example, the class was discussing the naked egg activity in which the egg shell is dissolved in vinegar in order to better observe
the changes in egg tonicity due to osmotic changes in the solution in which it is placed. Mrs. L was again driving the sensemaking and reasoning about evidence, but this time the source of evidence was a hypothetical experiment a student had suggested.

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<td>1</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>2</td>
<td>Marco</td>
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<tr>
<td>3</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>4</td>
<td>Violet</td>
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Episode 26

While this episode is very reminiscent of episode 25, the main takeaway here occurred in line 3. A student had just identified what he believed the result of this hypothetical scenario would be based on his understanding of osmosis, but Mrs. L was pushing the students to make the connection to observable results in an experiment. In line 3, she specifically asked, “what would we expect to see? What evidence would we look for to know that our prediction is true or not?” and in doing so, was emphasizing the role of empirical evidence in understanding phenomena. Even though the reasoning in this episode fell short of simple interpretation, the foregrounding of justification in knowledge building by Mrs. L was sending a message to the class as they co-constructed meaning.

The next episode again displays how Mrs. L pushed the students to rely on empirical evidence as a means for understanding and making sense of science. In episode 27, the class was discussing the various activities they had
done and identifying the knowledge gained from those activities. Edith, in line 2, described what the naked egg experiment was and what the students learned from that activity: that water moves from high to low concentration. At this point, we might characterize Edith’s talk turn as mid to low-level reasoning. She failed to incorporate the relevant information, but included a simple interpretation of the results, suggesting a level 2 reasoning. Edith’s interpretation was not what Mrs. L was looking for, and in line 3, Mrs. L asked Edith to take a step back and provide only the relevant information from the observations. Mrs. L drove this conversation, conducting the sensemaking one line at a time starting with the basic observations from the egg activity.

<table>
<thead>
<tr>
<th>1Mrs. L</th>
<th>What observation did we make for the egg?</th>
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<tr>
<td>2Edith</td>
<td>We had put it- you showed us the egg that was in vinegar for two days. And the [shell] of it had completely wiped off. And then we put in corn syrup for another two days and then the water from it went out so it went from a high concentration to a low concentration.</td>
</tr>
<tr>
<td>3Mrs. L</td>
<td>Okay. So what did the egg look like at first?</td>
</tr>
<tr>
<td>4Edith</td>
<td>It was bouncy and squishy.</td>
</tr>
<tr>
<td>5Mrs. L</td>
<td>Okay. Was it full of water of kind of deflated?</td>
</tr>
<tr>
<td>6Edith</td>
<td>It was full of water.</td>
</tr>
<tr>
<td>7Mrs. L</td>
<td>Okay. And then after we put it in the corn syrup, Daisy, what does it look like today?</td>
</tr>
<tr>
<td>8Daisy</td>
<td>It- the um, water had come out of the egg.</td>
</tr>
<tr>
<td>9Mrs. L</td>
<td>What did the egg look like?</td>
</tr>
<tr>
<td>10Daisy</td>
<td>The egg was deflated.</td>
</tr>
</tbody>
</table>

Episode 27
In line 8, when Daisy gave Mrs. L another simple interpretation of the data ("water had come out of the egg"), Mrs. L again had Daisy step back and only provide the observable information. Perhaps Mrs. L's goal here was to help students distinguish between observations and implications, but in line 11, Mrs. L asked for an interpretation, which both Daisy and Edith had supplied previously. These interactions indicate that both Daisy and Edith were capable of interpreting results and exhibit their epistemic agency in attending to reasoning about evidence in the classroom, but Mrs. L was not allowing space for student agentive voice outside of her authority. It is also possible that Mrs. L found that directing student sensemaking was more productive for the class as a whole, but as we have seen in Daisy’s and Edith’s interpretations of the egg activity, students are quite capable of directing this on their own.

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<tr>
<td>11Mrs. L</td>
<td>Deflated. Okay. And now we're putting it back in the water and let's see what happens. So that goes under patterns or observations. And then you guys are already starting to make sense of it. What does this mean? When this cell deflates and then re-plumps up, what is that telling us? Why is this happening? What's- what's the big picture here? What does this prove?</td>
</tr>
<tr>
<td>12Pandora</td>
<td>In the onion cell, it, um, when we put the saltwater on it, the saltwater has a lower concentration than the water inside the cells, so-</td>
</tr>
<tr>
<td>13Mrs. L</td>
<td>Lower concentration of…?</td>
</tr>
<tr>
<td>14Pandora</td>
<td>Water</td>
</tr>
<tr>
<td>15Mrs. L</td>
<td>Of water, right.</td>
</tr>
<tr>
<td>16Pandora</td>
<td>So the water in the onion cell will go out to the lower concentration of water in the saltwater. And when you put freshwater on it,</td>
</tr>
</tbody>
</table>
Freshwater has a higher concentration of water than inside the cells, so the water will flow into the cell membrane.

17 Mrs. L: Okay, so the big picture is what can water do?

18 Pandora: Water can move higher to lower concentration.

19 Mrs. L: Through a...

20 Pandora: permeable membrane

Episode 27 (continued)

Furthermore, after Mrs. L asked “What does this prove?” in line 11, Pandora responded by referencing yet another experiment and identifying the relevant information. After prompting by Mrs. L, Pandora also provided an interpretation of those results, which fits with the current egg activity (line 18, 20). What is so remarkable is that Pandora referenced another source of data, the onion cell, and was able to make the connection between the two activities, thus exhibiting sophisticated attendance to justification. Although Mrs. L was acting as the epistemic authority in this episode, it is clear that the students could interpret data in the absence of prompting.

This episode continues in line 21. If taken alone, lines 1-20 would exemplify mid-level complexity in terms of justification attendance; together with lines 29, we find that Mrs. L and her students were capable of sophisticated attendance to justification. Again, in lines 21-29, Mrs. L maintained her epistemic and sensemaking authority, driving the students to the conclusion by doing the cognitive heavy lifting herself.

21 Mrs. L: So that means cell membranes can... What do cell membranes do? Elliot.
Mrs. L engaged Elliot in a discussion about what a permeable membrane is and why it is important (lines 21-24), and while Elliot provided an explanation in line 24 by drawing upon the information from the recent experiments, Mrs. L was clearly looking for something more complex. She continued to drive the conversation in line 25 by rhetorically asking, “Don’t we need to keep some of the stuff in the cell?” and then probing deeper by asking, “What kind of things do we want to get out of the cell?” Red provided a logical but incorrect claim, and rather than push Red to reason about her explanation, Mrs. L instead returned to the driver’s seat by providing Red with a reminder (line 27), and then by reassuming explanatory authority (line 29).
Altogether, episode 27 is a sophisticated example of justification in the Biology 2 classroom in several ways. First, students could interpret data with little to no prompting, suggesting student buy-in in terms of using empirical evidence as a source of scientific knowing (Edith, Daisy). Second, students were capable of making unprompted connections across activities (Pandora), further indicating complex epistemic attendance. Third, with the teacher’s assistance, this particular episode transitioned from simple to complex interpretation of evidence (lines 21-29), which suggests that although Mrs. L’s scaffolding may have been unnecessary in some classroom moments, her support was essential in others as the class co-constructed meaning.

As we consider the attendance to justification in the Biology 2 unit as a whole, it is important to remember that while this particular epistemic consideration was not as foregrounded in the unit, the times when it was present are crucial to understanding the overall co-construction of meaning. For example, I have presented several episodes in which Mrs. L clearly prioritized evidence as a means for making scientific knowledge available to students. Although the students rarely exceeded level 2 interpretations of sources, Mrs. L’s emphasis on data was reflected in the examples in which students attend to evidence, whether real or hypothetical, and attempt to find meaning. Together, the co-constructed meaning from Biology 2 was one in which data in particular provide a basis for understanding how things work.

*Nature of account: Mrs. L and the students determine the account of the knowledge product.* The division of cognitive work as the class was unpacking
the phenomenon of digestion is slightly skewed toward Mrs. L in the Biology 2 unit (Figure 9). Although the students and Mrs. L attended to the nature of account about equally, Mrs. L tended to engage in more complex reasoning and provided heavy scaffolding for students as they reasoned. As I discuss the division of mechanistic work in this section, I will present a few examples of Mrs. L taking the lead, but I will also spend time highlighting student-centered examples to support the claim that students were actively engaged in the co-construction of meaning that prioritized complex reasoning about the phenomenon.

In episode 11, we start with an exchange between Mrs. L and Pandora in which they were discussing the account of how and why digestion occurs in the stomach.

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<tbody>
<tr>
<td><strong>1Mrs. L</strong></td>
<td>Why do we have all these acids and enzymes secreted by our bodies? Why is that important? Pandora?</td>
</tr>
<tr>
<td><strong>2Pandora</strong></td>
<td>Because if we didn't have our stomach the bolus would just go straight into our small intestines.</td>
</tr>
<tr>
<td><strong>3Mrs. L</strong></td>
<td>Okay. And what's the purpose of food?</td>
</tr>
<tr>
<td><strong>4Pandora</strong></td>
<td>The purpose of food is to get nutrients to our bodies.</td>
</tr>
<tr>
<td><strong>5Mrs. L</strong></td>
<td>Okay. And if our bodies need the nutrients, what part of the body needs the nutrients?</td>
</tr>
<tr>
<td><strong>6Pandora</strong></td>
<td>Cells</td>
</tr>
<tr>
<td><strong>7Mrs. L</strong></td>
<td>Cells. Okay. And if I want my cells to get the nutrients, what does the food need to be like?</td>
</tr>
<tr>
<td><strong>8Pandora</strong></td>
<td>It needs to be microscopic.</td>
</tr>
<tr>
<td><strong>9Mrs. L</strong></td>
<td>It needs to be microscopic. Okay.</td>
</tr>
</tbody>
</table>
Episode 28

The class had previously been unpacking the “how” of the question, which can be fairly straightforward for students as it is mostly content-driven. The “why,” or the reasoning behind the mechanism, is sometimes more difficult and not always foregrounded in the classroom. To her credit, Mrs. L was diligent in prioritizing both aspects of mechanistic thinking in her classroom, and episode 28 is one such moment. Pandora provided a simple account of why it is important for acid to break down food in the stomach (line 2), but Mrs. L found her response to be shortsighted. After all, why would it matter if undigested food traveled to the small intestine? Mrs. L wanted Pandora and the rest of the students to understand the implications of stomach digestion beyond simply making it possible for the next step of digestion to occur, and so she provided very clear supports as she helped Pandora in this episode. In line 4, Pandora understood that food provides nutrients for our bodies, but Mrs. L wanted her to specifically name cells as the critical factor needing those nutrients (line 5). Then, in line 7, Mrs. L set the groundwork for Pandora to make the next step in reasoning, “what does the food need to be like?” In this episode, Pandora was obviously an active participant who was reasoning about why stomach digestion is important, but it was Mrs. L who was making this reasoning possible and thus doing the mechanistic work. While it is the goal for students to achieve this with little support, Mrs. L’s work here was critical as the students learned not only the mechanism of digestion, but also the value of reasoning about the mechanism.
As I have discussed the previous epistemic considerations in the Biology 2 unit, there has been an evident theme of prioritization of mechanistic reasoning, and episode 28 further solidified that. In episode 29 we revisit a topic of interest from both the Audience and Justification sections: William's onion cell model. While previously I had unpacked the comments about his model (Keshawn's distinction between show and explain (Episode 24), Howard's different perspective regarding purpose and content (Episodes 24, 25), Mrs. L's reminder of the link between evidence and understanding (Episode 26)), I unpack the actual content of his model in episode 29.

<table>
<thead>
<tr>
<th>1Mrs. L</th>
<th>William, would you show us what you had on Friday? So, you have-so, you've got three steps here. You have step one, an onion cell in water. Can you explain this, what-what we have here?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2William</td>
<td>What I mean by that was that the onion cell has water on it. So, when it gets in salt water, or regular water. The onion is on water, with salt water, or whatever water on it.</td>
</tr>
<tr>
<td>3Mrs. L</td>
<td>And then you have, number two, onion cell in salt water, and then I see where salt, salt, salt, salt, salt all around this, and then, um, is there a reason why you shaded this so darkly?</td>
</tr>
<tr>
<td>4William</td>
<td>When we watched the video that showed the, uh, that showed osmosis, it showed how the purple in the, you know, purple pigment, it showed it getting, uh, darker as it-as it became closer together. So, I showed that, like, when the pigment is all out, or all throughout the cell, it's like, a lighter color than when it, like, kinda you now, compact together, it becomes darker.</td>
</tr>
<tr>
<td>5Mrs. L</td>
<td>Can you also kind of clarify for me, I see this circle around it, and the word salt is inside that circle. What-what's this outer oval mean?</td>
</tr>
<tr>
<td>6William</td>
<td>The outer oval is supposed to be the [cell] membrane. I mean, yeah, and uh…</td>
</tr>
</tbody>
</table>
Throughout episode 29, William was explaining parts of his model and Mrs. L was asking him to elaborate on some of the choices he made in representation and why he might have made those choices. Recall, this model was constructed after William had observed the onion cell being washed with freshwater, saltwater, and again with freshwater to see the changes occurring to the cell. At the time, William did not have a complete understanding about the cell or what was happening inside it, but had built his model to make sense of the things he was seeing. This is obvious in lines 7-9 as Mrs. L asked William about the "blob inside of the membrane" and William was not sure exactly what that was, but was drawing what he could see. Additionally, although William did not fully understand the mechanism behind osmosis at the time, he drew upon this onion activity and another video from class (line 4) which he believed to have similar mechanisms as he was deciding how to represent the phenomenon. In line 10, we see that William was able to reason about the phenomenon with his
model, and in line 12, now that he had a more complete understanding, he knew what sort of changes he could make to help his model provide a more complete account of osmosis in the onion. While previously we had seen Mrs. L take charge in pushing Pandora to get at the “why” behind the phenomenon, here we see William trying to make sense of the “how.” Together, these episodes indicate that as Mrs. L and the students are co-constructing meaning, they are valuing mechanistic accounts, albeit at varying levels of sophistication.

Episode 30 is yet another example of how mechanistic reasoning was prioritized in the classroom. In this particular episode, Sheldon and Daisy had made a model explaining osmosis and were now joining partners Freya and Red to construct a consensus model.

<table>
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<tr>
<th>Episode</th>
<th>Dialogue</th>
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<tbody>
<tr>
<td>1Sheldon</td>
<td>Ok. so we drew- ours is kinda small but we drew like multiple cells and then like the pigment is like the um, membrane just to show the color of it, like show it better shrinking. So the salt is like the clear circles and then, as it passed over, there's not a lotta pigment. And then smaller than this cell with the water- with the freshwater going over it and there's much more pigment and it's larger. And we showed it shrinking and expanding.</td>
</tr>
<tr>
<td>2Freya</td>
<td>So here's a question that I have. I mean you guys are explaining it really well as shows down here, but it's not really showing me how. So… Do you by any chance know a way that we could make it show how?</td>
</tr>
<tr>
<td>3Daisy</td>
<td>Well that's why your model is incorporated so… okay, what is yours?</td>
</tr>
<tr>
<td>4Freya</td>
<td>I'm not exactly finished with it [LAUGHS] but um- She's not exactly finished with it either 'cause she's an overachiever.</td>
</tr>
<tr>
<td>5Red</td>
<td>I wrote uh- I wrote the entire explanation.</td>
</tr>
</tbody>
</table>
In line 1, Sheldon explained the model he and Daisy constructed, and in doing so, was attending to the nature of account by describing the factors involved in osmosis and then reasoning to some degree about those factors. In line 2, Freya commented that the model explains but does not show. I find it important to point out that Keshawn had made a similar comment regarding William's model, but in that case, he implied that to explain was more sophisticated than to show (Episode 24). In this case, it seems Freya had implied the opposite; or perhaps, she meant that Sheldon and Daisy's written explanation explains, but their diagrammatic model does not. Because students often use these words interchangeably and without a clear pattern or meaning, we place both words in the same category of informing or communicating with an audience. Nonetheless, the idea of communication implies that students must convey to the reader the meaning behind the model, which in this case was the mechanism of osmosis. Thus, in line 2, Freya attended to both audience and mechanism when she evaluated the model's diagrammatic representation as lacking the explanatory power needed to communicate how osmosis happens. Also exciting is the fact that in lines 2 and 3, Freya and Daisy were engaged in the spirit of collaboration by seeking out ideas from each other. While this episode is much shorter than the others, it exemplifies how the co-constructed prioritization of mechanistic reasoning had been embodied by the four students in this group.

In general, one might expect most classrooms to have a focus on understanding the mechanistic content behind scientific phenomena; however, the meaning co-constructed in the Biology 2 unit was set apart from traditional
learning landscapes. While Mrs. L was intent on students uncovering and explaining the “how” behind big ideas such as digestion and osmosis, she also found great value in students reasoning about “why” these things happen and in using models to accomplish that. From these episodes, we have seen how Mrs. L found it necessary to support students in explaining “why,” and although that aspect might pose a challenge for students, they bought into and sought new ways to explain “how.” In all, the co-constructed meaning in the Biology 2 unit as it relates to mechanistic work was one which prioritized the use of models to communicate how and why phenomena occur.

**Student Agency.** In the previous sections, I have presented data that showcase the extent to which the teacher and students were engaged in sophisticated epistemic thinking. Because they attended to the epistemic considerations in ways that suggest both student buy-in and teacher prioritization, I argue that the meaning being co-constructed in the Biology 2 classroom was meaningful to both students and to science. In order to more completely support that claim, I now present data that highlights how student agentive voice in the Biology 2 unit was indicative of co-constructed meaning that valued student epistemic agency (Figure 9).

In episode 31, Lindsay started by asking what seems to be a clarifying question, but it later transformed into her trying to make sense of the phenomenon of osmosis. Students had just finished observing the naked egg activity, and Lindsay was noticing that the membrane of one of the eggs had ruptured, leaving just the “skin.”
Episode 31

In line 5, Lindsay indicated that she was curious about how the membrane behaves compared to the entire naked egg. She came up with a hypothetical experiment and began to hypothesize about potential results: she suggested that the membrane would dry out if left out of the water, but that replacing it in the water could restore its normal function. This utterance is an incredible example of unprompted student sensemaking and epistemic agency. Not only did Lindsay have the agency to ask a question outside of the driving question for the activity, but she also was attending to justification (experimental design to test her ideas) and nature of account (wondering if osmosis affects the membrane and the naked egg in similar ways) at the same time. Furthermore, Mrs. L valued
Lindsay’s agentive voice and in lines 6 and 8, agreed to set up this experiment to see if Lindsay’s ideas are correct. This episode highlights how both Mrs. L and Lindsay valued empirical evidence as a source of knowledge as well as how Mrs. L valued student thinking.

Episode 32 is another example of students taking charge of thinking and sensemaking, and thus exercising an agentive voice.

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<tbody>
<tr>
<td>1</td>
<td>Elliot</td>
</tr>
<tr>
<td>2</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>3</td>
<td>Elliot</td>
</tr>
<tr>
<td>4</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>5</td>
<td>Jason</td>
</tr>
<tr>
<td>6</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>7</td>
<td>Jason</td>
</tr>
<tr>
<td>8</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>9</td>
<td>Elliot</td>
</tr>
</tbody>
</table>

Episode 32

In this episode, Elliot seemed to understand the concept behind osmosis, but was not sure about why exactly osmosis was necessary. Going back to Mrs. L’s push throughout this unit for students to explain how and why a phenomenon occurs, it seems Elliot was clearly buying into the need to understand the why of osmosis. Rather than provide him a straightforward answer in line 4, Mrs. L pushed Elliot and the other students to think about why our cells are capable of allowing some things to pass across the membrane. Jason joined in Mrs. L’s
sensemaking, and by the end of this episode, Elliot had a better idea about the importance of molecule movement across membranes. In this particular exchange, we see how Elliot voiced his need to provide a more complete explanation of the phenomenon, ergo he was attending to the epistemic consideration of nature of account. Not only is this indicative of how Elliot had internalized the importance of mechanistic reasoning, but he was able to exercise that agentive voice and negotiate a better understanding of osmosis with Mrs. L.

Alfred returned to Lindsay’s earlier question and hypothesis about membrane function in episode 33 when he posed his own question and hypothetical experimental design, thus exemplifying student agentive voice.

<table>
<thead>
<tr>
<th>Alfred</th>
<th>Uh, I was wondering, like, if you were able to take that egg membrane that you had and, like, perfectly seal it halfway through a cup and pour water in it, and then you put salt on one side, would you be able to see the water get higher on the other side?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mrs. L</td>
<td>Yeah, because it's a membrane it allows some molecules in, some molecules out. There's stuff called, um, dialysis tubing, which is a semi permeable membrane. It's very, very, very small holes in it, and you can do an experiment where you can allow water in and out, and um, glucose in and out, but starches can't. Starches are very big molecules, and don't fit in the little, tiny holes in the membrane.</td>
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</tbody>
</table>

Episode 33

Like Lindsay, Alfred was seeking to negotiate a better understanding of membranes and osmosis using attendance to justification. While Lindsay was trying to figure out if the membrane functioned similar to the whole egg even when it was separated, Alfred here was posing a new experiment to provide more support for explaining osmosis. What is unique is that he was bringing
together the onion cell (using salt) and the naked egg (using sugar) activities to know whether or not the naked egg will behave the same in salt water as it did in an excess sugar solution. Alfred was making sense of osmosis and exercising epistemic agency in developing an experiment to test his claim, and he had possibly been bolstered in doing so after witnessing Lindsay’s earlier agentive exchange with Mrs. L; however, rather than taking time to test Alfred’s hypothesis, Mrs. L provided him with an explanation that bridges the gaps in Alfred’s understanding. Perhaps Mrs. L believed that the students could make the connection between water behavior in salt and sugar concentrations because both activities yielded similar results and students had already established the size of these molecules. Regardless, in line 2 of this exchange, Mrs. L was silencing Alfred’s epistemic agency and instead driving the conversation using her own authority.

In every classroom, there is a balance between teacher authority and student agency; in the Biology 2 unit, I have shown how students were exhibiting epistemic agency and Mrs. L was either providing space for negotiation of ideas or is taking back control. In all three episodes I have highlighted here, there was a clear pattern of students pushing to become agents of their own epistemic thinking, which supports my earlier claim that the meaning co-constructed in the classroom valued student ideas. Although I have also shown an example of Mrs. L silencing Alfred’s epistemic voice, her negotiation with Lindsay and Elliot suggests that she was forming behavior patterns that valued student thinking and thus give further credence to my claim.
Meaning applied to final models. After examining the classroom data for evidence as to how the teacher and students are co-constructing meaning as they engage in a practice, I now look to the interview data to better understand how students are applying the co-constructed meaning as they build a model on their own. In previous chapters and earlier within this chapter I have provided an account of Mrs. L’s framing as she presented this modeling task to the students. Her original intent was for students to construct an infographic for explaining how diet and exercise contribute to disease states and then to share these infographics with individuals coming to the school’s annual science night. Some of this framing was evident in the classroom discourse (Episode 22). As I mentioned at the beginning of this chapter, the data suggest that students were drawing upon a source that was quite different from the co-constructed meaning as they engaged with their final model, and as I will explicate further in Chapter 6, I believe that students were drawing upon Mrs. L’s task framing instead. Based on the teacher’s and students’ attendance to the epistemic considerations and the negotiation of agentive voice in the classroom data, I concluded that Mrs. L and the students were co-constructing meaning that leveraged epistemic thinking as a primary component of modeling. As I present the interview data below, I will highlight trends in student ideas about their models that offer a very distinct perspective (Figure 9). Overall, the students tended to see their models more as devices of entertainment than explanatory representations of phenomena.

Epistemic Considerations. In terms of student attendance to the epistemic considerations as they discussed their models, most of the responses
were low level and did not exhibit the same level of sophistication as had been prioritized in the classroom co-construction of meaning. Generally speaking, student attendance to audience was mostly centered on informing or demonstrating to an audience that closely matched Mrs. L’s framing of the intended audience for the infographics in Episode 22. Students rarely used evidence in building their models, and when evidence was used, there was little to no reasoning attached to it. Finally, unlike the classroom experiences in which mechanistic thinking was prioritized, only about half of the students were able to reason about the phenomenon in their model despite additional prompting. Together, these data suggest that co-constructed meaning from the Biology 2 classroom was not applied as students built and presented their final models. I discuss these results in detail below.

**Audience: My infographic is to inform others.** When asked about the purpose of their model, all students gave low-level responses at least once throughout the entire interview, which corresponded in part with the attendance patterns seen in the classroom data (Figure 9). As evident in Figure 10, the purpose of demonstrating or informing was most commonly cited as compared to the other possible reasons for constructing the final model, with 25 total mentions of using the model to inform across all 18 interviews. None of the students sought to use their model to help someone understand nor to persuade an audience, and only two students said their model could be used for sensemaking. Although a great deal of the classroom attendance to audience was focused on using models to inform, both Mrs. L and the students also
implicitly brought up using models to make sense of complex ideas as they encountered questions in the classroom. As such, it may be surprising that so few students believed that the goal of their infographic was for anything other than demonstrating phenomena; however, I believe that this figure suggests that factors other than the co-constructed meaning contributed to students’ engagement in the final model.

Figure 10. Students’ interview responses reflecting attendance to why in the audience epistemic consideration in the Biology 2 unit. Students were asked to discuss the purpose of their models. Some students responded with answers in more than one coding category; all of these responses are reflected in the figure. (n=18)

One possible explanation for the deviation from the patterns co-constructed in the classroom is that of Mrs. L’s ideas and motivation for altering the Biology 2 unit. Mrs. L framed the final model both in classroom discourse and through rubrics and other media as an infographic for students to share at
science night. I discussed this approach to the final model as I explained the classroom data, because it contributed to the co-constructed meaning that the students and Mrs. L were developing as they navigated practices in the Biology 2 unit. I presented various episodes throughout earlier sections that supported this kind of framing. As expected, students adopted at least some aspects of this audience framing as they built and discussed their final infographics, with a few key caveats that suggest a more complex story.

Overall, the pattern of who students thought their model was for matched Mrs. L’s framing of “people at science night” (Figure 11).

Figure 11. Student ideas about who could use their Biology 2 model. Circles represent the various coding categories and the lines from student names to the circles indicate a student response that fits the category. The most commonly cited sources are shaded. Some students responded more than once; these responses are indicated with lines that converge at the student’s name.

For some students, this manifested as “anyone,” whereas others were more explicit that the “other” was specifically the science night audience. For example,
Leanne responded that she made her model for “anyone that is going to the science room during exhibition night,” and Margery said her model was “basically for exhibition night,” both of which clearly attend to Mrs. L’s framing. Even when the student did not explicitly answer the question and were thus considered to have an audience that was “not obvious,” there were clues within the interview that suggested the student had the science night audience in mind. For example, Violet did not provide a specific audience, but based on her other responses, we might infer that she adopted similar framing (Episode 34). In explaining the goal of her model, Violet provided a brief insight to her intended audience: someone who wants to learn in a fun and interactive way (line 3), which could be used to describe the patrons at science night.

<table>
<thead>
<tr>
<th>Violet</th>
<th>Well what we were going to do was we were going to make a trifold model with each of the respiratory system and zoom in with the little flaps that were represented here. And just too small there. And then we were going to explain all of it in a video. Make it like a science video.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewer</td>
<td>Ok. So what was the goal of your model?</td>
</tr>
<tr>
<td>Violet</td>
<td>So what we wanted to do was kind of create a model that was very interesting, like you could interact with it and just kind of make it fun but also teach you stuff.</td>
</tr>
</tbody>
</table>

Episode 34

While the majority of the students bought into the framing of constructing their final infographic for people going to the school's science night, another portion of the students believed their model was for the teacher. For example, Elliot indirectly cited the teacher as his main audience as he was completing his infographic (Episode 35). When asked about why he included certain ideas in his
infographic (line 4), Elliot responded that those were the requirements and it was necessary for him to include them (line 7). This suggests that as he and his partner were constructing their final infographic, they were not thinking about the people at science night learning from the infographic, but rather they were thinking about how the teacher would grade this project. Additionally, in line 9, he indicated he was driven mainly by the deadline, further suggesting that Elliot did not apply the co-constructed meaning from the classroom discourse, choosing instead to draw upon Mrs. L’s framing of the infographic as a task. I embark on a more explicit dissection of these ideas in Chapter 6, but for the purposes of answering the driving question here, the data support the idea that students did not fully apply the co-constructed meaning to their final models.

| 1Elliot | We were trying to answer actually multiple questions. We were trying to answer how the body systems are connected - the three that we're learning right now, respiratory, circulatory, and digestive. And then we were trying to see how we actually use the food. And then...we were just supposed to use some common sense and stuff in the product that we made I guess. |
| 2Interviewer | Ok. Alright. And then you said you also included some other concepts? |
| 3Elliot | Yeah. Some key words, like the mouth and cellular respiration and things like that. |
| 4Interviewer | Ok. And why did you include those? |
| 5Elliot | Because those were key things that we needed to explain what - like, how the body uses food. |
| 6Interviewer | Ok. Alright. So you guys talked about it and those were some words that you needed to include to be able to explain this fully? |
Elliot: Actually, those were some of the requirements. So we needed those words in it.

Interviewer: Alright. So if those weren't part of the requirements, would you have included them anyway?

Elliot: We actually kind of missed a few…. Because we were just trying to - because we were under pressure on getting to the deadline.

Episode 35

In looking at the students’ ideas about the who and why aspects of their infographics, there is a more convincing case regarding the source of meaning students applied to their final models. While in the classroom Mrs. L spent a great deal of her time pushing students to focus on the explanatory power of their models for the benefit of an audience, there were several instances in which students – and Mrs. L – acknowledged the ability of models to help students make sense of puzzling ideas. Only two students believed their final infographic was useful in a sensemaking capacity, and even then, it was in addition to the larger goal of informing an audience (Figure 10). Consider Meg’s attendance to audience in episode 36. Although she saw some value in the model to help her put together the ideas and “reinforce” the sensemaking she had already done, her larger goal was “to show other people” how the body systems are connected. This suggests that in terms of the final infographic, very few students used it as an opportunity to achieve more sophisticated goals such as persuading science night patrons of the importance of diet or using the infographic as a valuable personal sensemaking tool.

Interviewer: Ok. So what’s the goal of your model?
<table>
<thead>
<tr>
<th>Meg</th>
<th>To show pretty much how - I think it's just mainly how they're connected. A little of how your body uses food, but it seems to have a lot of other stuff, too.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewer</td>
<td>Alright. So to show to someone else how your body works together? Or to yourself?</td>
</tr>
<tr>
<td>Meg</td>
<td>Yeah, to -well, it's also a little bit to reinforce what I already learned, but it's mainly to show other people.</td>
</tr>
</tbody>
</table>

**Episode 36**

Furthermore, while the classroom attendance to audience was focused mainly on informing via sophisticated attendance to mechanistic reasoning, in their interviews, students instead focused on the creativity of their models. For example, in episode 34, Violet spent time discussing the physical components of her model and then pushed the idea that her goal was to create an infographic that had the power to entertain as well as inform. I will spend a great deal of time unpacking this trend in the Nature of Account section later in this chapter; for now, my main goal has been to present an argument for the shifts in co-constructed classroom meaning and applied meaning. Despite the presence of several similar patterns in audience attendance, the larger tapestry suggests that as students built and discussed their final models, they relied on a source of meaning that contrasted sharply with the meaning they co-constructed in the classroom with Mrs. L.

*Justification: I do not use evidence to justify the ideas in my infographic.*

Similar to the patterns of audience attendance in the interview data seen above, attendance to justification was limited and low-level at best as students discussed the construction and use of their final infographics in the Biology 2
unit. And, like the attendance to audience seen above, this trend represented a shift away from the co-constructed classroom meaning that prioritized data as a source of knowledge (Figure 9). As students responded to two questions about the evidence they used to construct their model, they attended to both the source and reasoning aspects of the justification epistemic consideration. During the interviews, 14 students explicitly mentioned that they did not use any evidence as they were constructing their infographics, and eight students cited authoritative sources (Figure 12), which comes as a stark contrast to the foregrounding of empirical evidence in the classroom discourse throughout the Biology 2 unit. Additionally, these patterns are quite different than those seen in the Earth Science 2 unit, in which every student cited a source after prompting.

Figure 12. Sources of evidence cited by students in reflective interviews in the Biology 2 unit. Some students responded with more than one category, and thus were counted twice. (n=18)
In terms of student attendance to the second aspect of justification, reasoning, the pattern in interview data was similarly low (Figure 13). Of the 14 instances in which students indicated they used no evidence to support their infographic, unsurprisingly none of the students included any type of reasoning. Some students, such as Bob, seemed to have confusing ideas about what constituted evidence, and thus fell into this category. In episode 37, Bob claimed that the written explanation that accompanied his infographic counts as evidence because it is explains the pictures he drew, which was the actual evidence. Not only is this not representative of common scientific thought regarding sources of knowing, but it also is not representative of Mrs. L’s guidance in classroom discourse. Based on the exchanges in the classroom, Mrs. L prioritized empirical evidence as a scientific way of understanding the world; Bob’s conception of evidence here did not reflect that co-constructed meaning of justification.

<table>
<thead>
<tr>
<th>Bob</th>
<th>Probably the explanation just because people might take the model as a different way, when the explanation explains exactly what's going on. So people might take this as they might not know exactly what it is, but the explanation does it explains what that is, it's more convincing that way.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewer</td>
<td>So does the explanation have evidence in it or is it the evidence itself?</td>
</tr>
<tr>
<td>Bob</td>
<td>Well the evidence itself is the pictures, but I think that this has evidence in it since it's explaining what the evidence is.</td>
</tr>
</tbody>
</table>

Episode 37

Bob’s response was concerning in that it drew upon personal representations of knowledge as justification for itself rather than simply representing the construction of ideas based on evidence. In short, Bob’s model
was more than just a representation to him; the representation was a justification that the ideas within it were true. On the other hand, equally concerning was the fact that many students explicitly stated they used no evidence to construct their final infographics. For instance, Leanne said, “I don’t think we had a lot of evidence in our first draft because we were focused more on the storyline and making it more explanatory and more reasoning and claim than evidence.” Not only is this suggestive of a step away from the co-constructed classroom prioritization of data, but it is also quite telling about Leanne’s priorities as she engaged in the construction of the infographic: entertainment. Again, this is reminiscent of the underlying themes I presented in the Audience section in which students were more concerned about the physical salience of their models rather than the explanatory or mechanistic power of them. Similarly, Meg said, “Actually, I don’t think I used -I really used any evidence. I think I should probably fix that. Because I think I explain a lot of how it's doing what it's doing what it does, but not really why.” Although Meg indicated that she focused on mechanistic reasoning in her model (which matches the classroom co-constructed meaning –and which I will explain in the next section), she also was admitting that justification was not part of her construction process; however, unlike Leanne, Meg experienced cognitive dissonance and wished to change her model to include more evidence.
Even when students used evidence, they were unable to justify those sources at sophisticated levels (Figure 13). For example, consider Scott’s response (Episode 38). In this episode, Scott recalled that the evidence he and his partner used came from authoritative sources, but rather than justify how those pictures and information from books helped convince them the ideas were true, he said that he and Frederick simply decided “what was good” for the product they were creating. This kind of response is not at all reminiscent of the co-constructed meaning from the classroom discourse, and it seems evident that Scott and Frederick drew from another source of meaning as they constructed this final infographic. In fact, even Scott’s word choices, such as how he “compiled most of the text” suggests that the reasoning behind the inclusion of
his sources was not so much to persuade, make sense, or even demonstrate a phenomenon to an audience via a model, but rather to provide condensed information in a digestible way via a website. Although I will later argue about how word choice impacts student interaction with a model, here I will merely reflect upon how Scott had obviously deviated from the classroom co-constructed meaning in terms of justifying ideas.

| Scott | We used pictures, we used information that we have learned from books. And we compile- I compiled most of the text and sent it to Frederick and gave it to him and he kind of went through it and told me what was good and what wasn't as good for the website. |

Episode 38

Some students used empirical evidence, similar to what was prioritized in the classroom, but again, none were able to provide sophisticated reasoning about those sources (Figure 13). In episode 39, Sam cited empirical evidence, “projects,” as something that helped him understand what was happening in the digestive tract. Although he pointed out a specific activity in line 3, he did not connect this activity with his understanding of the digestive system and he did not link the activity back to the ideas presented in his infographic. Despite his reference to a specific activity, we do not consider this to be reasoning, and thus Sam does not exhibit anything beyond low-level attendance to justification.

| Sam | Well, we did different projects in this unit. And those projects help describe -or help -it helped us know what was going on in each system. So really, that helped me out because then I realized what each part of the digestive system did or the respiratory system did. |

| Interviewer | Ok. Alright. So when you say projects, what does that mean? |
Well, in the digestive system, we were given different -like different foods and we were supposed to see which one dissolved better, like starch or like water or sugar.

Episode 39

Although the classroom discourse did not push for sophisticated justification of ideas, the trends in the Biology 2 interview data were sharply contrasted with the classroom co-constructed meaning. Mrs. L and the students prioritized empirical evidence as a way of understanding the physical world; they prioritized evidence as a means of justifying ideas although they did not necessarily engage in the reasoning aspect to fully realize the extent of this epistemic consideration. Conversely, based on the interview data, students were not carrying these ideas over to their final infographics. Overall, students generally failed to engage in epistemic thinking regarding the justification of ideas in their infographics. Additionally, even when students could identify sources of evidence, they failed to form links between the evidence collected in class and the ideas they were presenting in their infographics. Together, this not only suggests a failure to apply the co-constructed classroom meaning to the final knowledge products, but it further suggests that the teacher was not supporting these students in epistemic thinking throughout the entirety of the unit.

*Nature of Account: My infographic provides a partial account of the phenomenon.* Throughout the classroom discourse in the Biology 2 unit, Mrs. L foregrounded mechanistic explanations via “the how and why” of a phenomenon, suggesting sophisticated attendance to nature of account as Mrs. L and the students co-constructed meaning. In the students’ final infographics, we fail to
see the application of this co-constructed attendance to mechanistic reasoning (Figure 9). Overall, there was a split between students who provided partial reasoning about the account of the phenomenon and students who provided little to no reasoning about the account (Figure 14), which did not reflect the classroom co-constructed meaning.

Figure 14. Causal accounts of the phenomenon provided by students in their final models in the Biology 2 unit. Circles represent coding categories and are listed from left to right in order of increasing sophistication along the arrow. Lines to student names indicate students with interview responses coded in a particular category. Dotted lines indicate reasoning that occurred with incorrect accounts of the phenomenon. (n=18)

Most of the students attended to the nature of account epistemic consideration at low levels. In light of Mrs. L’s push for mechanistic reasoning in the classroom – and the students’ buy-in – we did not expect to see a shift toward less sophisticated attendance. For example, in episode 40, Edith merely named one factor involved in the conversion of food to energy: the three systems
involved. Despite additional prompting, Edith did not progress beyond a level 1 for mechanistic reasoning.

<table>
<thead>
<tr>
<th>Edith</th>
<th>I was trying to answer how and why your body -your body systems were connected. The cardiovascular, the respiratory, and the digestive system. I was trying to link those all together.</th>
</tr>
</thead>
</table>

Episode 40

Edith’s example was not one commonly found in student responses, but it did represent the lower anchor of the epistemic consideration, and as such, we would expect that the majority of students are reasoning at much more sophisticated levels by the end of the unit. Counter to what we expected based on content comprehension by the end of a unit as well as Mrs. L’s push for explanatory thinking in the classroom, the majority of the student responses were only slightly more sophisticated than Edith’s at a level 2. For example, Lindsay’s explanation of the phenomenon using her infographic was broken into three sections in episode 41. In lines 2 and 3, Lindsay followed the path of food from the mouth to either the toilet or the circulatory system. In doing this, she was naming two of the factors in the mechanism (food and its path, and the three systems), but was not reasoning about the connection between them, thus, this was only a level 2 response. What is unique is that in line 1, she explained how originally, she and her partner would meticulously draw the factors involved in the phenomenon, but then switched to using circles because “it’s easier and it’s more understanding [SIC].” This indicates that Lindsay has a more sophisticated view on the representative nature of modeling, which is a very desirable way of thinking as students become more familiar with the practice. Less promising was
Lindsay’s failure to use her model to reason about the connection between the factors, which we would expect students to be able to do as they become more familiar with the content and also because it was heavily foregrounded in the classroom.

<table>
<thead>
<tr>
<th>1</th>
<th>Lindsay</th>
<th>So in the digestive system, we’ve kind of broken it down because we're doing an info graphic. So we’ve broken it down into 3 parts. And so instead of draw -like whenever we first started, we would use - we would take our time drawing food. But instead, we just decided to draw circles for each one to represent what they are instead of words because it's easier and it's more understanding.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>So we had the food and then we had that it goes - the food is broken down by your incisors or your molars, then it goes to saliva and then your esophagus, your stomach for chemical digestion. Then it goes to chyme and your small intestine, and then it breaks apart.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>You have the villi, which is in the small intestine, the bloodstream, and then the circulatory system, and that’s where the arrow goes. Or it goes to the large intestine, or the colon, and then the rectum, and then the toilet.</td>
<td></td>
</tr>
</tbody>
</table>

**Episode 41**

Frederick’s response provides another look into the kinds of ideas students had at reasoning of level 2 (episode 42). Just as Lindsay did, Frederick named the two factors involved in the phenomenon but failed to reason about the connections between them. More interestingly, rather than using his model to explain how food provides energy, Frederick used this as an opportunity to talk more about the physical features of his model, such as the layout of his website. The same basic interview questions were used in all three units, so it is interesting that students focused on the mechanism of the phenomenon in the Earth Science 2 unit, but in this unit were suddenly focusing more on the physical
features of the product in this unit. Again, this points to students drawing upon a new, more immediate source of meaning as they built their final infographics rather than drawing upon the co-constructed classroom meaning.

<table>
<thead>
<tr>
<th>Frederick</th>
</tr>
</thead>
<tbody>
<tr>
<td>So it gives like a little brief explanation of each body system. Like the digestive, the cardiovascular, and the respiratory. And it tells how it works and then as far it goes, and then there’s another page and it goes and it fits everything together and it tells how all the different systems connect to each other and then how we get the energy from the food.</td>
</tr>
</tbody>
</table>

Episode 42

Cal’s response was a much more sophisticated one, and is an example of a student naming and unpacking all the factors involved in the phenomenon (Episode 43). In a unit in which the teacher prioritized mechanistic reasoning, Cal’s response is the level at which we would expect most students to be reasoning; however, in this unit, it is the rarity. Episode 43 is an example of a student naming both the systems involved and the food and its path, and then unpacking the relationship among the factors. While I will not focus on exactly how Cal’s response fits the coding rubric, I will note that Cal frames his mechanistic account within the context of the physical features of his infographic. For example, Cal started his response by mentioning that his infographic was in the form of a trifold brochure and then providing the details of the three sections of that brochure. Although he was reasoning at a more sophisticated level than most of his peers, Cal shared a similar focus on the final product of the infographic, which we have seen in students at all reasoning levels.

<table>
<thead>
<tr>
<th>Cal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well, what we’re doing is a trifold brochure. And we’re having 3 sections that are saying that the digestive system, circulatory system, and</td>
</tr>
</tbody>
</table>
respiratory system. And we're putting a small text box at the bottom saying how this system connects with all the others and how some components of this have to tie in with the circulatory system. I have the digestive system and I'm saying how when you're eating your food from the mouth and how your saliva is incorporating with the food and how it's going down the esophagus and entering your stomach, through the duodenum, through the small intestine, and then it ties into the circulatory system where the villi absorb the nutrients which sends them to the bloodstream. After that, the part of it getting to your cell for food, the energy part, is a little bit done, but the respiratory system also has to do with the cell. When you're breathing in, the oxygen and the nitrogen- well the nitrogen, it's not really being used. And the carbon dioxide is basically waste because you're not using that as well. You're only using oxygen. Your oxygen will go into your bloodstream thru the alveoli, which is near your heart. And your lungs will pump big and it will go small again. It's for you to, you can be absorbing or inhaling the oxygen, which is then going to the alveoli, which then sends it to the bloodstream, which then enters the cell. So you need the energy, you also need the oxygen for your cell to survive, so that's how all 3 of these systems are all being connected. Like, we don't really have a model, but we have steps that are showing where and how it's happening.

Episode 43

In all, despite strong attendance to mechanistic thinking in the classroom discourse by both Mrs. L and the students as they constructed and critiqued models, students generally failed to reason about the phenomenon in sophisticated ways as they discussed their final infographic. Because students tended to frame their account in the context of the physical product, it seems as though they were prioritizing creativity rather than providing explanatory accounts. Additionally, the focus on the final product reflects the trends seen in audience and justification as well. Ergo, this is yet another epistemic consideration that was prioritized in the classroom discourse and abandoned in
the final knowledge product, suggesting that students were not supported in meaningful modeling throughout the entire unit.

**Summary of Findings**

The Biology 2 unit was quite different from the Earth Science 2 unit in several ways. First, Mrs. L and her colleague designed a new approach to the Biology 2 unit that culminated in a publicly shared infographic, and thus they added a more specific modeling focus throughout the chapter; the Earth Science 2 unit was essentially implemented as designed by the IQWST curriculum. This indicated to us as researchers that Mrs. L valued modeling and collaborative learning, but also that Mrs. L would be replacing some of the built-in IQWST scaffolds with some of her own. Second, because of the changes Mrs. L made to the Biology 2 unit, the students had vastly different audiences for the final models in the two units. In the Earth Science 2 unit, students had the freedom to decide on their own; in the Biology 2 unit, the audience was structured as patrons at science night. I believe this impacted student engagement in the final model, and I will unpack this claim later in Chapter 6. Finally, and most importantly, we see drastic differences in the ways students engaged with their final models in the two units, which ultimately suggests shifts in the way Mrs. L was supporting students across the units.

In this chapter, I presented evidence from the Biology 2 classroom discourse that showed the co-construction of meaning that prioritized epistemic thinking (Figure 9). As Mrs. L and the students engaged in practices, there was a strong focus on using models and explanations to both inform and make sense
phenomena. Mrs. L also brought up the framing of the final model several times in the classroom discourse, which seemed to drive some of her discourse moves with respect to modeling. While sophistication was relatively low-level, both Mrs. L and the students prioritized empirical evidence as a means of understanding phenomena, and data-gathering activities drove several of the sensemaking and modeling activities in the classroom. Finally, there was a clear foregrounding of mechanistic reasoning at work in the co-construction of meaning. Mrs. L and the students spent a great deal of talk time engaged in mechanistic work, and Mrs. L emphasized students unpacking the “how and why” of phenomena as they constructed models. In all, as I have explained earlier, the classroom discourse data suggest that Mrs. L and the students co-constructed meaning that reflects authentic science engagement and promotes student buy-in.

In moving to the interview data, and thus examining how students applied that co-constructed meaning, we can more clearly see how Mrs. L failed to sustain that meaningful engagement in the practices across the entire Biology 2 unit (Figure 9). For example, even though students adopted Mrs. L’s audience framing for their final infographics (which matched the classroom attendance patterns relatively closely), some students failed to find value in the model beyond rote task completion. Furthermore, despite attendance to evidence as a source of knowledge in the classroom, a majority of students did not consider evidence at all as they constructed their final infographic. Those who included evidence were unable to reason about those sources at a sophisticated level. Finally, in what I would consider to be one of the most interesting shifts, most
students failed to unpack the nature of the phenomenon in sophisticated ways despite Mrs. L's push for explanatory thinking in the classroom. Even though the students attended to the nature of account in classroom discourse and engaged in mechanistic work as they participated in modeling activities, many students abandoned this focus as they discussed their final infographics. Rather than provide a mechanistic account of the phenomenon, students tended to focus on the creative aspects of their infographics. As a result of these findings, I argue that students did not apply the co-constructed classroom meaning to their final infographics in the Biology 2 unit. Thus, to answer the research question with regard to the Biology 2 unit, although Mrs. L supported meaningful engagement in modeling during the classroom discourse, this authenticity was not sustained across the entire unit. I will provide a more detailed analysis of these trends and their implications in Chapter 6.
Chapter 5: Earth Science 3

In this chapter, I unpack the final ways in which Mrs. L supported students across the final unit in my study. Again, I will address how meaning was co-constructed by Mrs. L and the students in the classroom discourse and then address how the meaning was applied as students discussed their final models in the interviews. Like the Biology 2 unit, the evidence from the classroom discourse and the student interviews in the Earth Science 3 unit suggests that although Mrs. L and the students co-constructed authentic meaning in the classroom, the students failed to apply such meaning in their final models, instead drawing from more procedural sources. Below, I briefly outline the patterns in epistemic considerations and student agency that support this claim. These patterns are also represented in Figure 15.

- **Audience. Who will use our model and how?** In this unit, Mrs. L and the students co-constructed meaning that prioritized the purpose of knowledge products primarily as tools for persuasion of an audience but also to make sense of puzzling ideas. In the reflective interviews, students saw their models as tools for communication.

- **Justification. How do we justify the ideas in our model?** Data and reasoning were foregrounded in the classroom co-constructed
meaning, but students often failed to use evidence to support their final models.

- **Nature of account.** What kind of answer should our model provide? Mrs. L and the students split mechanistic work in the classroom equally, and the co-constructed meaning prioritized mechanistic unpacking. In discussing their final models, only about half of the students were able to use their models to unpack the account of the phenomenon.

- **Student Agency.** In this unit, students frequently exercised their epistemic agentive voices by attending to the epistemic considerations, asking questions, and pushing for authority as scientific thinkers.

**Figure 15.** Classroom co-constructed meaning, the teacher approach to the final models (a duct tape model), and how the students applied meaning to their final models in the Earth Science 3 unit.

In Figure 15, I share patterns in classroom co-constructed meaning and the meaning students applied to their final duct tape models. In this particular unit, the classroom attendance to the epistemic consideration of audience was sophisticated, with prioritization of knowledge product goals as to Sensemake and to Persuade (convince an audience of an idea). Students used their final
models to Inform (demonstrate to an audience). Just as in the other two units, *Data* was a prioritized source of evidence in the classroom, but students abandoned this as they discussed their duct tape models. Reasoning about evidence in the classroom ranged from a level 0 (no justification) to a level 3 (a multiple source interpretation), with mainly level 2 (simple interpretation), but ranged from a level 0 to a level 1 (identify relevant information) as students discussed their models. Again, both the teacher and students engaged in mechanistic unpacking (nature of account) and students exercised epistemic agency (bold border, Figure 15). In their discussions about the final models, students reasoned about the nature of account at levels in the middle of the progression. Recall that Mrs. L’s approach to the final model was a heavily modified version of a curricular knowledge product and stood apart from the knowledge students were actively building in classroom activities related to IQWST, which I represent here with the double bar (Figure 15). While the meaning applied to the final models was much less sophisticated than the co-constructed meaning, it played a larger role in students’ construction of their final models, which I represent here with a larger, darkly shaded rectangle (Figure 15). In the following sections, I unpack the context of the Earth Science 3 unit, the data analysis from the classroom discourse, and the data analysis from the student interviews.

**Data Summary**

To better understand how Mrs. L supported students across the Earth Science 3 unit, in this section I will summarize the kinds of data we collected. I
first share the overall design of the unit and the specific context of the three videos I highlight in the data analysis section. Next, I move to describing the modifications Mrs. L made to the design of the unit, as this was the most drastically changed of all three units I studied.

**IQWST unit design.** What sets this unit apart from the other two is that Mrs. L made heavy modifications to the overall structure of the unit design and implementation. While here I will discuss the original intent of the IQWST unit design and then go into the details regarding the lessons we taped, I later explain the extent to which Mrs. L modified the lesson and provide a few insights to her rationale for these changes. The Earth Science 3 unit was divided into four learning sets culminating in a written explanation that explains how earth’s surface is changing; we specifically collected video data during the first learning set and conducted student interviews at the end of the unit. Although I later describe the context of these classroom days, I provide a summary of the videotape content for each of the three focus days in Table 5.

In the first learning set, students were introduced to the driving question and spend time making sense of patterns in geological data such as earthquake and volcano distributions. All of our classroom videos came from this learning set, particularly the first three lessons during which the students were engaged in the practices of analyzing and interpreting data, and asking questions. The second learning set took students deeper into the causes behind earth’s changing surface by engaging students in simulations and experiments to make sense of convection. Students compiled the data and make sense of it in the third
learning set as they wrote scientific explanations to explain geologic patterns.

Finally, in the fourth learning set, students would have been constructing models to explain case plate movement, refining their scientific explanations, and applying those explanations to new situations. It is from this learning set that Mrs. L developed her idea for the final model. Below, I describe the classroom interactions from the three data collection days during this unit. Although there were a variety of practices throughout the unit, Mrs. L removed those from her lesson plans, therefore eliminating our need to collect data.

Table 5

*The nature of classroom activities and attendance to Epistemic Considerations on three videotaping days in the Earth Science 3 unit*

<table>
<thead>
<tr>
<th>Epistemic Consideration</th>
<th>Lesson 1-1, Day 2</th>
<th>Lesson 1-2</th>
<th>Lesson 1-3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration (Minutes)</td>
<td>Duration (Minutes)</td>
<td>Duration (Minutes)</td>
</tr>
<tr>
<td>Audience</td>
<td>0</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Justification</td>
<td>6</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Nature of Account</td>
<td>16</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Nature of Activities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off-Task</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Group work</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Whole-Class Discussion</td>
<td>32</td>
<td>41</td>
<td>43</td>
</tr>
<tr>
<td>Individual work</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Time</td>
<td>45</td>
<td>41</td>
<td>43</td>
</tr>
</tbody>
</table>

*Lesson 1-1, Day 2.* The very first lesson of this unit started with students looking at a map of locations of earthquakes and volcanoes. Although we joined
the students on the second day of this lesson, the first day only involved a brief introduction to the map and the driving question. On Day 2, the students took a more in-depth look at these patterns and began to make sense of them as a class. This particular lesson started with Mrs. L reminding students of the driving question board and Lesson 1-1’s driving question regarding making sense of the patterns in volcanoes and earthquakes. Mrs. L and the students briefly went over the patterns they encountered the previous day regarding volcanoes, and then the students began to make predictions about why those patterns exist and where earthquakes might be found in relation to the volcanoes.

As students were making sense of these ideas, they shared predictions and their conceptions about some of the terminology they use. For example, some students brought up the idea of “fault lines,” and were then tasked with making sense of what those terms mean. This class day is a rich example of attendance to mechanistic unpacking and justification of ideas. Throughout the discourse, Mrs. L frequently pushed students to justify their claims and provide more complex explanations of the patterns. The sensemaking discourse shifts between teacher-led and student-led, and these overtones dominate the duration of the 45-min class.

**Lesson 1-2.** After the sensemaking discussion about volcanoes and the predictions about earthquakes in Lesson 1-1, the class moved on to viewing actual earthquake data in Lesson 1-2 to see if the data fit the predictions. As students were viewing the earthquake data as a class, Mrs. L asked for input regarding observations or patterns that stand out. Much of the sensemaking here
was guided by Mrs. L, but she frequently provided opportunities for students to take the lead, as she rarely asked leading questions but instead would push students to explain their ideas more completely.

The flow of this lesson closely followed the IQWST design in which the teacher supports students in noticing a variety of key patterns in earthquakes and volcanoes and then beginning to make predictions about why these patterns exist. Again, the classroom discourse was dominated by sensemaking episodes, but mechanistic thinking and justification of ideas frequent the discussion. About 40 minutes was spent on examining the global maps of data. Mrs. L ended the class by announcing the groupings for the final modeling project and answering related questions.

**Lesson 1-3.** The first 10 minutes of Lesson 1-3 were spent engaged in a discussion about a Daily Prep question. These questions were Mrs. L’s way of initiating student thinking before the class had officially started, and while these were quickly completed most days, the discussion on this particular day was slightly more involved. Afterward, Mrs. L moved to introducing the data for the day and the goals for data analysis. In this lesson, which drew on the patterns from Lessons 1-1 and 1-2, students investigated the relationship between elevation and the data from earthquakes and volcanoes. The students made claims about the links between volcanoes and mountains, using evidence to back up their ideas, and then shifted to thinking about mountains and earthquakes. Next, Mrs. L sought student ideas regarding plate boundaries, and it was during
this portion of the class that students brought up the idea of Pangea and interlocking “puzzle pieces.”

Again, justification, mechanistic reasoning, and sensemaking were key themes across this classroom video. The students frequently shared ideas and Mrs. L scaffolded these discussions with prompts designed to spark new ways of thinking about data. At the end of this forty-minute classroom video, Mrs. L shifted into setting up the next lesson in which students would examine evidence regarding continental drift.

**Teacher Approaches to the Unit.** As I mentioned earlier, Mrs. L made a variety of changes to the way she approached this unit in the classroom. To start, Mrs. L found great value in the Lesson 9 activity in which students would be instructed to choose a geological location and spend a few days constructing a 3-dimensional model to explain the geological phenomenon behind that location using common household items. Initially this lesson was planned as a way to scaffold students as they began constructing written explanations to explain the cycling of rock material as well as applying that explanation to one geologic site. Mrs. L had a strong background in earth science, specifically geology, and also bought into the value of modeling in the classroom. Over the years, she had been teaching this unit, she eventually redesigned an approach that removed the final written explanations and instead culminated with a more polished version of the model in Lesson 9. At the time of our data collection, Mrs. L had established the final Lesson 9 models as 3-dimensional “duct-tape models” that drew the attention of others at the school as being a showcase of science, engineering,
and artistic prowess in the eighth grade. Furthermore, Mrs. L had started a sharing program with other eighth grade classrooms across the nation in which her students would construct and send these plate tectonics duct tape models to other schools for the purpose of learning. To support this program, Mrs. L made changes to the unit to allow for more time constructing professional-looking models.

Because the reputation of these duct-tape models was so vast, students were aware of the general concept long before the start of the unit. Nonetheless, Mrs. L spent time framing the project and preparing students for the amount of work necessary from the beginning of the unit and throughout the class. On the first day of the unit, Mrs. L set the stage by establishing groups, locations, and other such details (Episode 44), thus underlining the importance of this particular model.

<table>
<thead>
<tr>
<th>Mrs. L</th>
<th>And then I’m going to tell you what your groupings are for the project, and we’re gonna start talking about like what kinds of things we can include in our models. Once we’ve learned where these things are. Like we’ll find out your location. Are you gonna have to represent volcanoes and earthquakes and mountains in your location?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Episode 44</td>
<td></td>
</tr>
</tbody>
</table>

Mrs. L built in a great deal of scaffolding for the success of these models in terms of professionalism and engineering. To do this without lengthening the unit, Mrs. L had to omit a variety of other activities from the curriculum. She planned days in which students would work in their groups to view models and websites explaining their geological sites, design and draft initial models, work with local engineers to perfect the movement of their 3-dimensional models, and
finally prepare the finished product. IQWST activities that did not serve to support this process were eliminated, and thus we discovered that Mrs. L planned to remove almost all of the curricular activities that included engagement in practices. In all, only three practice-based lessons remained in the teaching plans, and it was on these three days that we collected the data I will be showcasing here. Although this unit offered much less discourse data to be analyzed, I find that the decisions behind the removal of data-collection days is still a valuable source of understanding the patterns in co-constructed meaning across the Earth Science 3 unit.

**Analysis of Findings**

In this section, I unpack the patterns of meaningfulness in the classroom and student interview data based on attendance to the epistemic considerations. Recall that I focus on three specific classroom videos from this unit as I analyze how Mrs. L and the students engaged in the classroom discourse to co-construct meaning. Then, I move to an analysis of the meaning students applied to their final model. Finally, I end this chapter with a brief summary of the findings from the Earth Science 3 unit.

**Classroom Co-Constructed Meaning.** Overall, the meaning co-constructed in the Earth Science 3 classroom was authentic to both science as the epistemic considerations were prioritized, and to students as they bought into the need to think epistemically (Figure 15). To determine this, I examined both the attendance to the epistemic considerations and the negotiation of roles and authority as students exercised their epistemic agency in the classroom. The
data I present below suggest that there was sophisticated attendance to the epistemologies in the practices by both the teacher and the students. Additionally, the students pushed for more agency, and the teacher provided more opportunities for these occasions. First, I will unpack attendance to each of the epistemic considerations and then move to a discussion about student agentive voice in the classroom.

**Epistemic Considerations.** In this section, I put forth several examples from the classroom data in which the teacher and students were engaged in epistemic discourse. As a whole, the students and Mrs. L exhibited sophisticated attendance to the epistemic considerations, but tended to focus primarily on justification and mechanistic unpacking. Below, I explain how the patterns in these classroom episodes contributed to our overall understanding of this unit as an example of co-constructed meaningfulness.

**Audience:** Our knowledge products are used to persuade and make sense. Although attendance to audience was not explicitly foregrounded in the classroom video data, there was tacit attendance to this epistemic consideration as Mrs. L and the students navigated the need to provide evidence for their claims. As they were engaged in making sense of the volcano and earthquake data, Mrs. L and the students frequently brought up the ideas of persuasion and constructing convincing arguments, which we considered as attendance to the consideration of audience. In doing this, together they were co-constructing meaning that prioritized engagement in practices for the purposes of sensemaking and persuasion (Figure 15).
In the first episode I unpack from this unit, one student had brought up the idea that at one time the continents likely fit together because of the way they are shaped. Rather than acknowledge the correctness of that statement and inform students on the history of plate tectonics, Mrs. L instead began a demonstration in which she ripped a sheet of paper in two and drops them at opposite sides of the classroom. Next, she asks students if the shape of the rip is enough to say they belonged to the same sheet at one point (Episode 45). Throughout this episode, there is an obvious theme of being convinced by evidence despite Mrs. L never actually saying the words. For example, in line 1, when Mrs. L asked “Is that enough for me to know…” she was not using know in the less sophisticated way of being informed; she was asking can I be convinced by that evidence alone? When students provided her with additional ways of confirming the claim, Mrs. L repeatedly asked “Is that enough?” and “How could I know?” which pushed students to find more convincing ways of determining the origin of the paper scraps. Additionally, Mrs. L’s link between evidence and knowing, suggests a much more sophisticated attendance to audience. By linking these two epistemic considerations, Mrs. L was supporting the students in co-constructing an understanding by which using evidence to convince is a normal procedure.

<table>
<thead>
<tr>
<th>Mrs. L</th>
<th>Is that enough for me to know it used to be part of the same sheet of paper?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>No</td>
</tr>
<tr>
<td>Violet</td>
<td>You have to put your name on it.</td>
</tr>
</tbody>
</table>
4Mrs. L | Oh! So you’re saying like I need other evidence. Like what-what other things could I do besides the fact that they fit together? Is making them fit enough?
---|---
5Class | No
6Mrs. L | What other-what other clues could I look for to see like, “Maybe this is part of that piece of paper over there?” Edith.
7Edith | you need to know the name and see who’s might be it, like on the upper left-hand corner. Like if it was Leo's and you thought it was Sam's, you could -
8Mrs. L | Well, how could I know if it’s Leo’s or Sam? How do I know it belongs to them? Like what kinds of things could I look for on this piece of paper to tell that it belongs to that piece of paper?

Episode 45

In the next episode, Mrs. L framed the classroom engagement as sensemaking and also provides space for student agentive voice (Episode 46). As a follow-up to the paper activity, in line 1, Mrs. L reminded students that “we’re trying to figure out: how did the earth look in the past?” Later, when she reiterated Elliot’s question in line 3, she was again attending to the purpose of engagement in the practice as sensemaking. Although she replied “you’re wanting to know” in line 3, the use of *know* is more than the low-level idea of being informed; Elliot had a burning curiosity brought about by the patterns in the data and he wanted to figure out more. Throughout this episode, Mrs. L was framing the classroom activities as being to make sense of ideas, which we consider to be sophisticated attendance to audience. Furthermore, Mrs. L was again attending to the use of evidence in being convinced of the origin of the continents, and she also acknowledged Elliot’s epistemic agency in determining a direction for sensemaking. Together, the attendance to audience in episode 46
indicates that Mrs. L was actively engaged in prioritizing sophisticated attendance to the epistemic consideration of audience.

<table>
<thead>
<tr>
<th></th>
<th>Mrs. L</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>We’re trying to figure out how did the earth look in the past? You guys are noticing that these things match up. People have noticed that they match up for centuries. People started first making maps after we had this transatlantic exploration. People noticed that a long time ago. So you’re just like, “They look like they match up. They must’ve been together.” Elliot, you were saying yesterday -what was your big question?</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Elliot</td>
<td>Like, why does like the things move and stuff?</td>
</tr>
<tr>
<td>3</td>
<td>Mrs. L</td>
<td>Yeah, like really? Do you think centuries ago, people thought that, “Oh, these just happen to be the same shape. They must’ve been together.” But now they’re 3,000 miles apart. Like how do you move an entire continent 3,000 miles? You’re wanting to know where on earth did this energy come from?</td>
</tr>
</tbody>
</table>

**Episode 46**

In yet another example of Mrs. L linking audience, justification, and student agency, we see how Mrs. L was working to cultivate sophisticated engagement in the epistemic considerations.

<table>
<thead>
<tr>
<th></th>
<th>Mrs. L</th>
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<tbody>
<tr>
<td></td>
<td>That’s really cool. That’s really neat to think about. We need to know some more information before we can determine that. Like is it gonna keep moving in this direction forever? Or would something happen to make it change its direction? That’s a great question.</td>
<td></td>
</tr>
</tbody>
</table>

**Episode 47**

In episode 47, Mrs. L was responding to a student's question about continental drift in the distant future. For the purpose of this example, the exact student question is not essential to the understanding of Mrs. L’s attendance to the epistemic considerations. The important detail in episode 47 is that it shows again how Mrs. L was actively providing space for student agency and linking
sensemaking to evidence when she said, “That’s really cool...We need to know some more information before we can determine that.” While Mrs. L could have deferred the question for a later time or deflected the question with a quick correct answer, she instead worked to construct meaning in which audience and justification are closely related.

While most of the episodes here have focused on the ways in which Mrs. L solely constructs meaning that we assume the students can either reject or accept, the larger picture is that Mrs. L was providing a framework for meaning that students could build upon as the class continued. We see that happening in episode 48 when she discussed the seemingly outrageous claims of geophysicist Wegener. Mrs. L set the stage, but in line 2, it was Pandora who responded with the necessity of using evidence to support claims. Furthermore, Mrs. L again linked evidence to the goal of convincing. This episode suggests that while Mrs. L was scaffolding sophisticated attendance to audience, the students were buying into it and preparing to contribute to the co-construction of meaning.

| 1Mrs. L | He is somebody who noticed that these things seem to fit together, and we’ll listen to a/an excerpt from a book called The Short History of Nearly Everything and you’ll hear about, historically, how Wegener was kind of laughed at. People didn’t believe him. ‘Cause if you’re gonna make a claim… |
| 2Pandora | You gotta have evidence. |
| 3Mrs. L | You gotta have evidence, right? So if we’re gonna claim that these continents used to be together, we have evidence besides the fact that they just look like they fit. Did that-is that convincing enough? |
| 4Class | No |

Episode 48
Overall, despite being more implicit and interconnected to other epistemic considerations, the attendance to audience in the Earth Science 3 unit was quite sophisticated. Mrs. L worked to support the students in co-construction of meaning that focused on using practices for sensemaking and persuasion. While most of the attendance was generated by Mrs. L, the students actively absorbed and eventually began to participate in co-construction of meaning with regard to aspects of audience. Because the discourse highlighted here came from the very beginning of the unit, I argue that the heavy attendance by Mrs. L is to be expected. In comparing the sophisticated attendance to audience in the classroom via using evidence to convince or make sense of ideas to Mrs. L’s framing of the final knowledge product as to inform (episode 45), it becomes clear that there may be discrepancies between the co-constructed classroom meaning and the meaning applied to the final model. Regardless, the consistent reiteration of sophisticated audience attendance by Mrs. L suggests that she was supporting students in the co-construction of meaning that prioritized knowledge construction to convince or make sense.

*Justification: We use data to justify our ideas.* As Mrs. L and the students co-constructed meaning in the classroom discourse, they frequently attended to justification, which suggests a strong prioritization of evidence during knowledge construction. Together, Mrs. L and the students focused on data as a primary source of evidence and generally reasoned about that evidence at a level 2 (Figure 15). In the examples I present below, I show how both the students and
Mrs. L attended to this epistemic consideration in ways that indicate sophisticated co-construction of meaning.

In episode 49, Mrs. L had just asked students for their ideas about the borders of plates, and Howard was sharing his thoughts. Although Mrs. L never explicitly asked students to justify their reasoning, Howard provided a level 1 reasoning based on the patterns in the data he has been seeing.

<table>
<thead>
<tr>
<th>1Mrs. L</th>
<th>...might be the edges of the plates? Okay. Howard, what do you think?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Howard</td>
<td>Also like those like ridges in like the Atlantic and the Pacific might be where plates are, because to create those, something has to be causing them to move.</td>
</tr>
</tbody>
</table>

**Episode 49**

This brief episode shows that some students were buying into the need to justify ideas even without prompting, and despite Howard’s lower-level response, it indicates that he found value in this way of epistemic engagement. In episode 50, when Sam asked a question, Mrs. L prompted him to reason for himself. Upon Mrs. L’s push to think deeper, Sam explained his reasoning based on the patterns he observed between the mid-Atlantic ridge and the San Andreas fault line that led him to his original question. Between episodes 49 and 50, we can see how Mrs. L was supporting students in justifying their claims so that it becomes a more natural response.

<table>
<thead>
<tr>
<th>1Sam</th>
<th>Would the mid-Atlantic ridge be considered a fault line?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Mrs. L</td>
<td>What do you think?</td>
</tr>
<tr>
<td>3Sam</td>
<td>Because, like the San Andreas Fault, it's kind of like the same structure…</td>
</tr>
</tbody>
</table>
Episode 50

Student buy-in to epistemic thinking about the justification of ideas can also be seen in Episode 51, as Alfred presented his own ideas regarding plates and the composition of the surface of the earth. Mrs. L had just asked a question about whether or not plates contained ocean and land or just one. Elliot provided a claim in line 2, and Mrs. L moved on to ask Alfred about what he thought.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1Mrs. L</td>
<td>What about plates? Here-here-a plate-is a plate just made of a whole continent? Is it just made of ocean? Can it have both ocean and continent on it? What do you think?</td>
</tr>
<tr>
<td>2Elliot</td>
<td>Both of them.</td>
</tr>
<tr>
<td>3Mrs. L</td>
<td>You-look at this, Alfred. What do you think about the plates? Can plates-?</td>
</tr>
<tr>
<td>4Alfred</td>
<td>I think like they're made up of ocean and water because if you look at Africa-</td>
</tr>
<tr>
<td>5Mrs. L</td>
<td>Wait, when you say “of water,” are they made of water?</td>
</tr>
<tr>
<td>6Alfred</td>
<td>Oh well, like they’re-I mean- underneath the water.</td>
</tr>
<tr>
<td>7Mrs. L</td>
<td>The land that’s underneath the water. Okay.</td>
</tr>
<tr>
<td>8Alfred</td>
<td>Because, like, if you look at Africa, like in the middle where all those earthquakes are, I would think that would be the edge of a plate and like it kinda has the same shape as Africa. And it goes from the other side of Africa, and like around it.</td>
</tr>
</tbody>
</table>

Episode 51

In line 4, Alfred also gave his own claim (they are made of both) and what separates his claim from Elliot's is that Alfred went on to justify that claim because of the patterns he saw in Africa. Mrs. L interrupted Alfred's justification to check for a misconception and yet Alfred continued to reason about why he thinks plates contain both water and land based on the earthquake patterns. Not
only was Alfred spontaneously justifying his claim despite other students providing claims only, but Alfred was also doing so at a level 2 reasoning, suggesting that he bought into the need to back up his claims with evidence.

The next example provides a more in-depth look at the attendance to justification and audience seen in episode 46. Mrs. L had just ripped a piece of paper to demonstrate the idea that the continents were at one time together, and then she asked the students if “looking” like they fit together was enough to be convinced the two halves of paper belonged together (episode 52). I unpacked the attendance to audience in the section previously and briefly mentioned how Mrs. L was prioritizing evidence as a means of knowing or believing. Although the students were not directly involved in a practice, they were constructing knowledge around a hypothetical argument, which is why I highlight this particular episode. With Mrs. L’s support, the students achieved what we would consider a level 3 reasoning about justification. This means that despite the hypothetical nature of the exercise, the students were able to identify multiple means by which they could use evidence to determine the origin of the paper, for example: fit, handwriting, and font. While this had been obviously scaffolded by Mrs. L and possibly would not have happened without her support, this episode exemplifies the kind of meaning Mrs. L was interested in co-constructing with her students in terms of justification of ideas. She was helping students to understand the value of evidence and reasoning in persuasion and knowing, and based on the interactions in episode 52, we might expect this trend to continue as the group co-constructs meaning across this unit.
<p>| | |</p>
<table>
<thead>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>2</td>
<td>Student</td>
</tr>
<tr>
<td>3</td>
<td>Violet</td>
</tr>
<tr>
<td>4</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>5</td>
<td>Class</td>
</tr>
<tr>
<td>6</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>7</td>
<td>Edith</td>
</tr>
<tr>
<td>8</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>9</td>
<td>Leanne</td>
</tr>
<tr>
<td>10</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>11</td>
<td>Meg</td>
</tr>
<tr>
<td>12</td>
<td>Mrs. L</td>
</tr>
<tr>
<td>13</td>
<td>Elliot</td>
</tr>
</tbody>
</table>
14 Mrs. L | Okay. So kinda like matching up the shapes. So we’re looking-besides the fact that, “Oh, these look like they fit together-” |
---|---|
15 Elliot | Yeah |
16 Mrs. L | I wanna be more convinced that they used to be part of the same sheet of paper. So handwriting, the font. What else? |
17 Violet | Maybe if it has like um, like circles on the paper, if like-if you-when you like put the papers together, if the circles complete each other. |
18 Mrs. L | Oh! So if like-if this rip breaks a picture in half and then when I put it together, the picture is put back together, that would help me too. |

**Episode 52**

To see how Mrs. L’s foregrounding of evidence was adopted by students, we look back to episode 48 from the audience consideration.

1 Mrs. L | He is somebody who noticed that these things seem to fit together, and we’ll listen to a-an excerpt from a book called The Short History of Nearly Everything and you’ll hear about, historically, how Wegener was kind of laughed at. People didn’t believe him. ‘Cause if you’re gonna make a claim… |
---|---|
2 Pandora | You gotta have evidence. |
3 Mrs. L | You gotta have evidence, right? So if we’re gonna claim that these continents used to be together, we have evidence besides the fact that they just look like they fit. Did that-is that convincing enough? |
4 Class | No |

**Episode 48**

Again, Mrs. L set the stage for not only foregrounding sensemaking and persuasion, but also for the role of evidence in accomplishing those goals (episode 48). In line 2, Pandora was able to finish Mrs. L’s sentence, and this may be due in part to Mrs. L’s obvious foregrounding of evidence thus far in the
unit. Based on this interaction, we might expect for these patterns to continue as students apply the co-constructed meaning to their final models.

In all, the attendance to justification in the beginning of the Earth Science 3 unit was sophisticated in terms of Mrs. L's prioritization and the students' buy-in. In the first three lessons in this unit, Mrs. L had very clearly scaffolded evidence and reasoning as essential components in constructing knowledge and persuading an audience. The link she had obviated between justification and audience was unique to this unit; this connection was never explicitly made in the other two units, and this suggests that the co-constructed and applied meaning for Earth Science 3 will reflect that connection. Although I have highlighted many episodes exhibiting Mrs. L's attendance to justification, the student examples show how the students are capable of justification in unprompted situations and how the students are becoming aware of the emerging importance of reasoning about evidence. Together, the classroom discourse in the Earth Science 3 unit indicates that the co-constructed meaning prioritized evidence as a means to make sense and persuade.

*Nature of account: Mrs. L and the students determine the account.* Along with justification, attendance to mechanistic reasoning, or nature of account, was the most frequently attended epistemic consideration in the Earth Science 3 unit. While the other two units incorporated some very low-level teacher-student interactions, we saw a sharp decline in these types of interactions in this particular unit, which suggests increased sophistication. Compared to the other two units in this study, the more sophisticated mechanistic reasoning was done
by the teacher; however, this may be due to the fact we only collected data from the beginning of the unit when students had very little understanding of the phenomenon. Regardless, below I highlight examples of attendance to nature of account in the Earth Science 3 unit that support my claim that Mrs. L and the students co-constructed meaning that prioritizes mechanistic reasoning (Figure 15).

One of the ways Mrs. L supported students in co-constructing attendance to nature of account was by asking students to reason about potential mechanisms for explaining the phenomenon. In doing this, Mrs. L was not necessarily looking for a “correct” answer, but pushing students to consider mechanistic accounts based on observations and prior knowledge. Episode 53 is a clear example of how Mrs. L was cultivating early attendance to mechanistic thinking.

<table>
<thead>
<tr>
<th>1Mrs. L</th>
<th>...might be the edges of the plates? Okay. Howard, what do you think?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Howard</td>
<td>Also like those like ridges in like the Atlantic and the Pacific might be where plates are, because to create those, something has to be causing them to move.</td>
</tr>
<tr>
<td>3Mrs. L</td>
<td>Okay. So you’re talking about these like Frankenstein looking scars? Do you guys see these?</td>
</tr>
<tr>
<td>4Students</td>
<td>Yeah</td>
</tr>
<tr>
<td>5Mrs. L</td>
<td>Do you think those things Howard is saying might these be the edges of the plates?</td>
</tr>
<tr>
<td>6Gary</td>
<td>Maybe</td>
</tr>
<tr>
<td>7Mrs. L</td>
<td>So if that’s the case, if what you’re saying is true, maybe the edge of a continent where these scars are the edges of the plates. Then</td>
</tr>
</tbody>
</table>
how do you explain the volcano here? Is that on the edge of the plates....?

<table>
<thead>
<tr>
<th>8Pandora</th>
<th>It could be...</th>
</tr>
</thead>
<tbody>
<tr>
<td>9Student</td>
<td>Not necessarily.</td>
</tr>
<tr>
<td>10Mrs. L</td>
<td>Yeah, like how does a volcano form in the middle? If you said they're pulling apart or pushing together, is this a place where plates are pulling apart or pushing together?</td>
</tr>
<tr>
<td>11Violet</td>
<td>They could be being pushed underneath.</td>
</tr>
<tr>
<td>12Mrs. L</td>
<td>What's being pushed underneath?</td>
</tr>
<tr>
<td>13Violet</td>
<td>Like the plate could be pushed underneath another plate or something....</td>
</tr>
<tr>
<td>14Mrs. L</td>
<td>Oh, OK.</td>
</tr>
</tbody>
</table>

In line 1, Mrs. L had just heard from a student about his thoughts on plate boundaries and without evaluating that response, moved on to Howard's ideas. When Howard pointed out that he thinks ridges might be the edges of plates, Mrs. L helped the other students identify the location Howard was naming and then asked the rest of the class if they agree. Again, Mrs. L had not given Howard any evaluation for his idea; she was focused on eliciting student ideas about the phenomenon. In line 7, after students agreed with Howard's claim of ridges being plate boundaries, Mrs. L asked students to consider the claim in light of the evidence they have in front of them regarding volcano and earthquake patterns. She pointed out, “how do you explain the volcano here?” to get students thinking about potential accounts to explain the patterns by focusing on the how and the why behind the phenomenon (lines 7&10). Violet responded,
and with some support from Mrs. L, was able to elaborate on the account (lines 11 & 13). By not evaluating student ideas but rather pushing for mechanistic thinking, Mrs. L was helping students prioritize reasoning about a phenomenon as well as exercising their epistemic agency.

The next episode is an example of students buying into this way of thinking. In episode 54, Mrs. L was again asking for student ideas without evaluating them.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1Mrs. L</td>
<td>Okay. Pandora do you have a different idea?</td>
</tr>
<tr>
<td>2Pandora</td>
<td>I think earthquakes are actually caused by plates moving, does not have to be specific areas or just, plates just moving.</td>
</tr>
<tr>
<td>3Mrs. L</td>
<td>Okay.</td>
</tr>
<tr>
<td>4Violet</td>
<td>Is it along.... like since California gets a lot of earthquakes and they have to like - don't they earthquake proof their house? Does that mean like California is along like a plate thing....Since it has like that fault line?</td>
</tr>
</tbody>
</table>

Episode 54

Pandora provided a brief account in line 2, but did not attend to the nature of account in a sophisticated way. Similarly, by asking questions, Violet was not necessarily exhibiting sophisticated attendance, but when Violet presented her idea, she provided reasoning and evidence to support her claim. Both Pandora and Violet were attending to the mechanism of the account with very little scaffolding from Mrs. L, which suggests they are buying into the importance of mechanistic thinking even when they have a limited understanding of the actual phenomenon.
We see a similar situation in episode 55 when Elliot and Leanne were working in pairs to figure out the account behind how and why earthquakes occur. As they interact with each other to answer questions in their science book, not only were Elliot and Leanne trying to verbalize the patterns in the data, but they were also providing their ideas for why earthquakes are occurring in such patterns.

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</thead>
<tbody>
<tr>
<td>1</td>
<td>Elliot</td>
</tr>
<tr>
<td>2</td>
<td>Leanne</td>
</tr>
<tr>
<td>3</td>
<td>Elliot</td>
</tr>
<tr>
<td>4</td>
<td>Leanne</td>
</tr>
<tr>
<td>5</td>
<td>Elliot</td>
</tr>
<tr>
<td>6</td>
<td>Leanne</td>
</tr>
<tr>
<td>7</td>
<td>Elliot</td>
</tr>
</tbody>
</table>

Episode 55

For example, after Elliot described earthquakes as being most common around the Ring of Fire and in the same place as volcanoes, he reasoned that it is because they are near bodies of water (line 5). Leanne also added her idea that the patterns have something to do with being near edges (line 6), and then Elliot became more convinced in his account of how they occur ("because the plates are moving back and forth or something like that"). By reasoning about the how and why of earthquake patterns, Elliot and Leanne were attending to mechanistic
reasoning even in the absence of prompts to push this kind of mechanistic thinking.

Based on the unprompted attendance to mechanistic reasoning by students seen in episodes 54 and 55, the students were likely buying into Mrs. L’s culture of prioritizing nature of account. These episodes represent a larger pattern of prioritization of mechanistic thinking in the Earth Science 3 unit; however, because data collection occurred in the early stages of the unit and students had not yet constructed sophisticated accounts of the phenomena, there were still cases in which Mrs. L did the majority of the mechanistic work without student input. Regardless, the overall pattern of increased attendance to mechanistic accounts by both Mrs. L and the students suggests that they engaged in the co-construction of meaning that prioritized reasoning about the explanatory account of the phenomenon.

**Student Agency.** After examining classroom attendance to the epistemic considerations, I now shift to analysis of student agency in the classroom to provide a more complete account of the co-constructed classroom meaning in the Earth Science 3 unit. In this particular unit, we see an increase in students exercising their agentive voice through asking more complex questions and engaging with mechanistic ideas at a higher frequency (Figure 15). Because these interactions tend to follow a few distinct patterns, I only share a few examples to highlight the different ways in which Mrs. L and the students cultivated a landscape that foregrounded students as epistemic agents.
One such way of co-constructing meaning that prioritized student agentive voice is through Mrs. L creating opportunities for student ideas. In episode 56, Mrs. L actively sought student ideas about mechanistic reasoning without the goal of evaluation of those ideas, which allowed students to have space for sensemaking.

<p>| | |</p>
<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>1Mrs. L</td>
<td>So why do you think these volcanoes are in these patterns? What makes a volcano, like how does a volcano form? What do you know already about this stuff? Violet?</td>
</tr>
<tr>
<td>2Violet</td>
<td>Um, when the plates of earth kind of move up the others separate, um, magma will rise above and then will build up and cool and then will separate again and will build up and cool. So actually, a volcano’s kinda like an iceberg, it’s bigger at the bottom.</td>
</tr>
<tr>
<td>3Mrs. L</td>
<td>Okay. So does that mean where all of these volcanoes, are you saying this is places where the plates are pulling apart?</td>
</tr>
<tr>
<td>4Violet</td>
<td>Yeah.</td>
</tr>
<tr>
<td>5Mrs. L</td>
<td>Okay.</td>
</tr>
</tbody>
</table>

**Episode 56**

Mrs. L asked Violet about to make connections between her prior knowledge about volcanoes and the patterns the class is currently analyzing, which Violet did in line 2. As Violet talked through her ideas, Mrs. L helped her verbalize the key component of volcanoes occurring where plates pull apart, and rather than evaluate Violet’s explanation as correct or incorrect, Mrs. L simply validated the fact that Violet shared her idea with the class and moves forward with an “Okay” (line 5). By doing this, Mrs. L stepped back from her role as epistemic authority and acknowledged Violet’s ability to construct knowledge in the presence of her peers.
The next way that meaning was co-constructed in the classroom to give students more epistemic agency was through students offering new ideas unprompted and having those ideas be acknowledged as cognitive contributions. One example of this is when Freya added a new idea about plate movement without Mrs. L’s explicit request for student ideas (Episode 57).

<table>
<thead>
<tr>
<th>Freya</th>
<th>Couldn’t the oceanic plate be pushing underneath another ocean plate?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mrs. L</td>
<td>It could be. How could we-where are, like how many plates are in this area? Can you tell? Or maybe you don’t know how to tell yet.</td>
</tr>
</tbody>
</table>

**Episode 57**

At this point in the discussion, Mrs. L was preparing to move to a new prompt for observation of the data and Freya jumped in to give her own account of what might be happening during the phenomenon. Rather than dismiss or evaluate Freya’s idea, Mrs. L gave it credence by responding with, “It could be…” and then shifting to push Freya for a deeper, more mechanistic explanation by asking questions about how they could tell the number of plates in one area. In doing this, Freya was exercising her agentive voice and Mrs. L was allowing space for students to act as the cognitive authority in the classroom. Together, this supports the co-construction of students as valid epistemic agents during engagement in the practices.

The final pattern in terms of student agency in the classroom was when students asked more complex questions. In episode 58, Sam was noticing new patterns in the data and wants to know why these patterns arise. Many times, in
a classroom, we see how the teacher asks probing questions that point out interesting shifts in data; here, we see a student doing this.

| Sam | Um, now it seems like there's not a lot of earth-er-volcanoes-Like - there's not as many like earthquakes or volcanoes in like deeper parts of water. Why is that? |

Episode 58

By asking this question in class, Sam exercised his agentive voice, meaning he felt capable of doing the cognitive work of data analysis. Freya, too, did this in episode 57, and in her example, she took the next step of providing a possible mechanism. The way in which both Freya and Sam asked questions in class suggests that these students were comfortable in acting as cognitive agents during engagement in a practice.

In sum, both Mrs. L and the students collaborated in the Earth Science 3 unit to co-construct meaning that valued students as epistemic agents. As Mrs. L allowed non-evaluative space for students to work through ideas, students in turn practiced their roles as cognitive agents and together negotiated meaning that foregrounded student thinking. Along with the ways in which Mrs. L and the students attended to the epistemic considerations in the classroom discourse, the attendance to student agency indicates the co-construction of meaning that prioritized students as authentic science thinkers.

### Meaning applied to final models

Compared to the classroom co-constructed meaning that reflected authentic engagement in science practices, the meaning as students applied it to their final models was akin to a much more procedural resemblance. As students discussed the construction and use of their
final models, there was a distinct lack of attendance to some epistemic considerations and to others, there was very low-level attendance (Figure 15). Because the classroom discourse was rife with rich attendance to the epistemic considerations and instances of sophisticated student epistemic agency, I had expected the students to apply that co-constructed meaning to their final models, which would indicate that Mrs. L provided support for the students across the entire modeling unit. As a reminder, Mrs. L had modified the final modeling project to be a professional product to be sent to another school across the country; I approach the interview data with this in mind. Below, in discussing the ways in which students engaged with their final models, I show how students applied a different meaning to the practice.

**Epistemic Considerations.** With regard to all three epistemic considerations, the student attendance was markedly different than that seen in the classroom discourse (Figure 15). Whereas previously I provided an account in which Mrs. L framed the classroom engagement in terms of sensemaking and persuasion with a heavy emphasis on justification, here I give examples of student interviews that indicate low-level goals of informing in the absence of evidence. Additionally, despite the prominence of mechanistic reasoning in classroom discourse, the trends in unpacking the nature of account shift to less sophisticated attendance in the student interviews. Together, the student attendance to epistemic considerations in the final models suggests the application of meaning other than that co-constructed in the classroom.
Audience: My model is to inform other eighth graders. In the Earth Science 3 classroom discourse, Mrs. L had framed the goals of engagement in practices as to figure out and to convince, and she linked these goals with justification using evidence (Figure 15). Ergo, based on the data we collected, I argue that the co-constructed meaning prioritized these goals as students attended to audience. In looking at the interviews as students discuss their final models, there is no data to suggest students applied this meaning to the construction of their final models, but rather the students relied on Mrs. L’s more rote approach to the duct tape model.

In episode 44, I presented a brief look at how Mrs. L framed part of the final model project during the first few lessons in the unit. She intended to send the 3-dimensional models to another eighth grade class across the country learning about plate tectonics. Based on the number of references to audience goals as students discussed their final model, students adopted this framing rather than the co-constructed classroom meaning (Figure 16). In fact, despite the prioritization of practice engagement as a means to make sense or convince, no students reported these as salient goals during the construction of their final model.
Figure 16. Students’ interview responses reflecting attendance to why in the audience epistemic consideration in the Earth Science 3 unit. Students were asked to discuss the purpose of their models. Some students responded with answers in more than one coding category; all of these responses are reflected in the figure. (n=18)

Similarly, students latched on the idea that their models were to be sent to a specific audience for a specific purpose. Figure 17 displays the most frequently mentioned audiences along with the purposes of those models with respect to the audience.
Figure 17. Most commonly cited coding categories for who students perceived their audience to be along with the purpose of the model for that specific audience in the Earth Science 3 unit. Who categories are listed in no particular order; Why categories are listed in order of increasing sophistication along the arrow from left to right. Line thickness represents more commonly occurring links between who and why. Numbers indicate the exact frequency of these particular pairings.

Although we have distinct categories for “peer,” “other,” and “anyone,” based on the students’ responses, these three coding categories have very similar meanings to the students. For example, in episode 59, Gary considered his audience to be for “people who kind of what to learn more,” but he later clarified this to mean teenagers or peers, which matches Mrs. L’s model framing.

<table>
<thead>
<tr>
<th>Gary</th>
<th>Well, our model is for people who kind of want to learn more about like, how things are formed. Like, it's more of like a teenager kind of approach to it because like, it's not giving you word for word everything that's going on. It's giving you all the important things you need and a little bit more. Like, it tells you about convection cells in the mantle - that's not really something you cover as a kindergartner. And, like, we haven't really learned at a college level yet so we can't really do it to a high sense. So it's more for like a teenager/peer kind of thing.</th>
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<tbody>
<tr>
<td>Episode 59</td>
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</table>

Frederick, in episode 60 recounted that his model could be used by anyone, but it was specifically for another 8th grade class.

<table>
<thead>
<tr>
<th>Frederick</th>
<th>I mean, it's ....really for anyone that's going to use it. For this one in particular, I'm not sure who is going to, but I know it's going to an 8th grade class because there's not a lot out there to teach plate tectonics. But it's for anybody that really wants to learn about plate tectonics and how earth is changing.</th>
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<tbody>
<tr>
<td>Episode 60</td>
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</table>

Percy, too, named eighth graders in another school as his target audience, and informing was his main goal (episode 61). Note how all three episodes focused
on the low-level task of informing rather than using the model to convince others that continental drift occurs or to figure out why the plates are moving.

<table>
<thead>
<tr>
<th>Percy</th>
<th>Well, I think we're going to be sending it to schools to teach plate tectonics so they can have models to show people and show kids that are learning about plate tectonics and how it works.</th>
</tr>
</thead>
</table>

Episode 61

The low-level attendance to audience is not limited to just the three episodes I have shared here; Figures 16 and 17 indicate that these patterns exist across all 18 students. Given that Mrs. L prioritized sophisticated audience goals in the classroom discourse, that she presented a less sophisticated framing of the final model, and that students exhibited low-level attendance to audience as they discussed their final model, I argue that students did not apply the co-constructed classroom meaning to their final models in terms of audience. I will present the larger argument in Chapter 6; for now, I simply point out that the co-constructed meaningfulness from the classroom discourse was not maintained as students constructed and discussed their final models.

Justification: I use authoritative evidence to build my model. Justification and audience were closely linked in the classroom co-constructed meaning, and Mrs. L prioritized data and reasoning in her role in the discourse. As students discussed the nature of their justification in the final models, and therefore revealed their applied meaning, students failed to sustain the link between audience and justification. Furthermore, student attendance to justification was nominal at best and frequently relied on sources other than those prioritized in the co-constructed classroom meaning (Figure 15). In the examples I share in
this section, I focus on these differences as well as provide evidence to support the role of Mrs. L’s modified modeling approach in shifting students’ application of meaning.

As I mentioned earlier, empirical evidence was foregrounded in the classroom discourse and thus the co-constructed meaning. When students discussed the sources of evidence they used in the final models, empirical evidence was the third most referenced source behind authoritative evidence and not using any evidence (Figure 18). While this pattern represents a less sophisticated shift away from the complexity of classroom discourse meaning, it also represents a positive shift away from the patterns seen in the Biology 2 unit in which “None” was the most referenced category. Furthermore, students failed to reason about these sources in any meaningful ways (Figure 19). At first glance, moving away from not using any evidence while constructing the final model seems to indicate more sophisticated applied meaning; I argue that the trend in the Earth Science 3 final models is just as low-level as that found in the Biology 2 final models.
Figure 18. Sources of evidence cited by students in reflective interviews in the Earth Science 3 unit. Some students responded with more than one category, and thus were counted twice. (n=18)

Figure 19. Links between codes for source of evidence and codes for justification about that source in student interviews in the Earth Science 3 unit. Source circles represent coding categories and are listed in no particular order. Reasoning circles represent coding categories and are listed in order of increasing sophistication from left to right along the arrow. Line thickness and numerical values represent the frequency of links between particular sources and reasoning categories in student interviews.
When we coded students as not including evidence, it was generally for
one of two reasons: either the student verbally responded that no evidence was
used, or the student was confused about what constituted evidence. After the
Biology 2 unit, we added a question to the interviews to help mitigate this
confusion (*Did you learn anything in class that caused you to make changes to
your model?*) and found that students still did not produce responses that
reflected the co-constructed classroom meaning. For example, consider Scott
(Episodes 62 and 63). When we asked him first about the things he learned that
might have changed his ideas about plate tectonics, he merely responded with
the specific advice his partnering engineer gave him, suggesting that empirical
evidence did not play a large role in his understanding of the phenomenon
(Episode 62).

<table>
<thead>
<tr>
<th>Interviewer</th>
<th>Have you learned anything to change your model during the lessons?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scott</td>
<td>To change my model I think from the feedback the engineer gave us was to have more or less curved instead of just shape paths for the knob to go up and down because it stopped really showing how big the Himalayas really are.</td>
</tr>
</tbody>
</table>

*Episode 62*

Later, when we explicitly asked Scott about the evidence he used to construct
the model, he outright stated he did not use evidence, but then backtracked to
say the evidence was in the explanation (Episode 63).

<table>
<thead>
<tr>
<th>Interviewer</th>
<th>What evidence did you use to support your model?</th>
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<tbody>
<tr>
<td>Scott</td>
<td>The evidence we used was- like, I can't really explain it, it's we have an explanation of it, we don't have evidence for, we have an explanation like what this is showing like how it happens and what</td>
</tr>
</tbody>
</table>
this is showing, we have evidence for how it happens which is the convection currents moved India and Asia up and connecting them so went the convection currents pushed Indian Asia- The Indian and Asian, Eurasian plates together, they made Himalayan mountains by riding a convection current.

Episode 63

Margery provides a similar case (Episode 64).

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<tbody>
<tr>
<td>1Interviewer</td>
<td>So you don't use any evidence to explain your model?</td>
</tr>
<tr>
<td>2Margery</td>
<td>I think using- the evidence is the explanation. The explanation we are typing out in language arts.</td>
</tr>
<tr>
<td>3Interviewer</td>
<td>So ok. So you say you didn't use any evidence to support your model other than your explanation?</td>
</tr>
<tr>
<td>4Margery</td>
<td>Yeah</td>
</tr>
</tbody>
</table>

Episode 64

We do not consider an explanation of a phenomenon generated by a student during knowledge construction to be evidence, and therefore these students represent a portion of the class that did not attend to justification as they were constructing and discussing their final model.

Even when students used evidence, it was often done in low-level ways. For example, the trend towards use of authoritative sources does not indicate that students were attending to justification in ways that reflected the co-constructed classroom meaning. In fact, the most common authoritative source was online simulations or models that students used to design ideas for their own models —not to make sense of the phenomenon. Elliot responded that he used the models to help him design his own model for the Himalayas because those models showed him "how the Himalayas were forming" (episode 65).
Elliot

….there was some models on the board and uh, and it showed how like the Himalayas were forming and things like that and that kinda got the idea in my head.

Episode 65

If we applied the audience rubric to the model Elliot was using, we would score it as low-level attendance to the goal of informing. Similarly, Percy used the digital animations (likely the same as Elliot’s “models on the board”) to find inspiration for drawing and building his own model (Episode 66). The fact that Percy said “That's where I got most of it” suggests that after the first three lessons in which the class co-constructed meaning, modeling became a rote way to passively learn material.

Percy

We saw ani-like we looked at a lot of digital animations in class. That's where I got most of it. And then we learned about different kinds of plate subduction….Like how they subducted under and you had to draw models and stuff like that.

Episode 66

I could easily provide examples such as this ad nauseam, but I instead will move to an episode in which data and reasoning were used in the discussion of Frederick’s model (episode 67). In the first line, Frederick initially admitted to not using evidence as he constructed the model because it sounds as though he, like Elliot and Percy, looked at other simulations to find ways to represent the phenomenon. Interestingly, he provided an account of the phenomenon that hints at a hypothetical scenario (“if you go there…”). We asked him to clarify his lack of evidence, and in line 3 he confirmed this, but then continued on to reference data and then reason about that data at a level 2.
<table>
<thead>
<tr>
<th>Frederick</th>
<th>We didn't really use that much evidence to support the model. I mean...it's more of like, we've used more actually what's happening in there. Like, just the location in general in Africa where it's rifting. Like, if you go there, it's gotten -it's become a valley. There's lakes and things there that weren't there before because the crust is getting thinner and stuff's collecting.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewer</td>
<td>Ok. So- you didn't use actual evidence, you just looked at the location?</td>
</tr>
<tr>
<td>Frederick</td>
<td>Yeah. And then some -and then some other stuff is the red sea, like if you look at evidence of where Saudi Arabia -like, if you look at fossils and stuff from Saudi Arabia and Africa, they match together. So it makes you think that- so it kind of shows that Saudi Arabia was close. And the Great Rift Valley is really close to where that was. So you could think that Saudi Arabia and the red sea is what's going to happen down in Africa. And it's just going to keep happening....for as long as it’s there.</td>
</tr>
<tr>
<td>Interviewer</td>
<td>But you didn't really use that to support your model?</td>
</tr>
<tr>
<td>Frederick</td>
<td>Yeah. It doesn't fit as well. Didn't use that much evidence to explain it.</td>
</tr>
<tr>
<td>Interviewer</td>
<td>Ok. Why doesn't it fit?</td>
</tr>
<tr>
<td>Frederick</td>
<td>Well, because it's not necessarily relevant to this....The great rift valley in particular, but it sort of is. I just haven't thought about it.</td>
</tr>
</tbody>
</table>

Episode 67

This indicates that, just as I had concluded in the classroom discourse section, empirical evidence had at one point been prioritized as Mrs. L and the students co-constructed meaning. Again, in line 5 Frederick reiterated that the evidence failed to “fit” the model he was building and thus he did not use it, but upon reflection in line 6, he saw how it could possibly support his claims. Frederick’s episode suggests that although evidence had been foregrounded in the
classroom, it was eventually overshadowed by rote engagement in modeling and low-level goals for the students’ final models.

Because we were only privy to the first three lessons in the unit, we expected that adding a new question about what students had learned during class would not only help them identify the key pieces of evidence that were critical to their model, but also give us an idea of the activities that shaped their understanding of the phenomenon. The idea that engagement in this particular final model was influenced specifically by engineering advice and simulations occurring throughout the remainder of the unit rather than the sensemaking about empirical evidence cited in the first three lessons suggests that the co-constructed classroom meaning around engagement in a practice was easily overpowered by other factors. Quite frankly, it alone suggests that Mrs. L did not support students in authentic engagement across the entire unit; however, I save this argument for Chapter 6. For the purposes of this section, the examples I discussed here are evidence to suggest that the evidence-centric co-constructed classroom meaning was not applied by students as they built and discussed their final models.

Nature of account: My model provides a partial account of the phenomenon. Unlike the co-constructed classroom meaning, the meaning students applied to their final models did not necessarily reflect strong attendance to the nature of the account they provided to explain the phenomenon (Figure 15). Despite Mrs. L’s focus on mechanistic reasoning in the classroom discourse, as students discussed the construction and use of their
final models, not all attended to the mechanism in sophisticated ways. In this section, I provide examples of student interviews representing both the lower and upper anchors of this epistemic consideration. I also highlight interviews that suggest a more rote meaning was applied as students built their final models.

At the end of a unit, especially one in which Mrs. L pushed for mechanistic thinking, we expect that student attendance to nature of account will be accordingly sophisticated for the majority of students. The patterns we found in the data do not reflect this expectation, and we discovered that student responses were generally split between the higher and lower levels of the progression (Figure 20). I first share two more sophisticated examples.

Figure 20. Causal accounts of the phenomenon provided by students in their final models in the Earth Science 3 unit. Circles represent coding categories and are listed from left to right in order of increasing sophistication along the arrow. Lines to student names indicate students with interview responses coded in a particular category. Dotted lines indicate reasoning that occurred with incorrect accounts of the phenomenon. (n=18)

Meg’s interview represents sophisticated attendance to nature of account because she names the factors of tectonic plates and continental drift, and then
reasons about plate movement and convection current as being responsible for
the production of her specific geologic location (Episode 68).

| Meg | Well, how I see it is so there are two plates on each side. And then they pull apart and, well, they pull apart really slowly. And a bit of magma seeps out. And then it cools and hardens on top. And then it just, it forms new crust, I guess. And...I'm kinda bad at explaining, but...so then that just keeps happening over and over again. And then at the other end of the plates, like at the opposite end of the ridge, the -the plate is subducting because, well, it's going back into the mantle because the new crust that's being formed at the ridge is pushing that old crust out back into the mantle. And, well, I think that's basically it. |
| Interviewer | Ok. Can you tell me why -why are the plates moving in the first place? |
| Meg | Because of there's something called convection in the mantle and it's like there are different currents; there's not one big current. There are different current cells, I guess you could say. Convection cells that are circulating because of changes in density and temperature. So -so the core is heating up the mantle and then the mantle material that is closest to the core, since it's hotter, rises up and then the cooler material takes its place. And then after it- the hotter material cools down again and the cooler one is hot, then they switch places and it's just going in a circle. |

Episode 68

This is an example of a sophisticated student response, but one that should not be too far advanced from the typical response at this point in the unit. Kelly, too, gives a response that should be closer to what we would expect from students at the end of the unit (Episode 69). While she names both factors, she only unpacks one of those factors despite additional probing.

| Kelly | So...it's a ridge, obviously. And the plates are pulling apart because it's a divergent boundary. And every time the plates pull |
apart, magma from the core, or the mantle, rises in to the gap and it creates new crust and it continues that cycle.

Interviewer  Ok. Why are the plates pulling apart?

Kelly       Because convection currents in the mantle. The plates move in the direction the convection current is going, so if it's going to the right, the plate goes to the right. And the other piece is going to the left and so they're being pulled apart by the currents.

Episode 69

Meg’s and Kelly’s responses are innocuous enough and do not suggest that anything other than the co-constructed classroom meaning was applied as they constructed and discussed their respective models. On the other hand, Percy’s response indicates that the physical model might have interfered with his attendance to nature of account (Episode 70).

1Percy     How the Andes mountains work. So like how the- Andes mountain range- like how the plates, how the tectonic plates subduct under each other to make the mountain range….So what happens is, is the oceanic plate, which is what this part of models is going to be, the oceanic plate. Well, it subducts under a land plate. And that will kind of -and once it gets down far enough, magma will shoot up from the intruding plate and it will create mountains.

2Interviewer  Ok. So what causes this one to move?

3Percy    Well, the land plate is on a continental crust, like on land, will stay still and the other plate will be moving towards it. And because this one is more dense, it will cause it to subduct or slide under it.

4Interviewer  Ok. What makes this one move though? Why is it moving towards the other one?
Because, like the magma under it is moving in a circular direction -I forget what it's called at the moment. But so as the magma is moving, it's pushing this plate under it.

Ok. And then this one goes under because it's more dense?

Yeah. And we have it made out of hard foam and soft foam so we can -with our model so it can bend if we need it to….Different parts of the foam.

And then, so how- how do the mountains form?

The mountains form when magma, like- after the oceanic plate gets so deep, it -magma starts to build up and when it... it's just, the magma builds up and it almost kind of like pokes it, kind of, and it causes that magma to shoot up through the earth to -on the crust to where it will come up and it'll like come out of the earth, harden, erode, harden, erode, harden until you get these mountains.

Although Percy scored at the same level as Kelly, his account of the phenomenon was assisted by the probing questions of the interviewer.

Additionally, in line 7, Percy mentioned about the materials he and his partner used for the construction of the physical model. For the most part, this caveat had little to do with his explanation of the phenomenon, but rather served to foreground the model as a physical product rather than as a cognitive agent.

While one could argue that Percy made a complex decision to use materials that would support the nature of the account he was providing, I assert that in the context of the other student responses in this epistemic consideration as well as those in the audience and justification considerations, Percy was likely driven by artistic or engineering needs instead.
My argument that Percy was focused more on the product than the mechanistic process becomes clearer upon examining student responses that fell along the lower anchor of the progression. Upon asking Sam to explain his model to us, he named two of the factors involved in the phenomenon but in the context of the physical representation of the foam boards and duct tape (Episode 71).

<table>
<thead>
<tr>
<th>Sam</th>
<th>Um, well with just the plate moving, it helped us make like an actual track way of how it was supposed to go, so the hotspot would be stationary so now it will just stay - like this one, it would just stay still there, but then this would move overtop of it, which would cause - like that would explains how the plate actually moves over the hot spot and cause it to erupt, and not just the mantle [pretty much standing there]</th>
</tr>
</thead>
</table>

Episode 71

Similarly, Edith provided only one of the factors because her main goal was explaining the mechanics of her model rather than the phenomenon behind it (Episode 72). In thinking about Percy’s response in the context of Sam’s and Edith’s, it seems that many of the students were concerned first with the engineering aspect of the final model rather than the co-constructed classroom attendance to mechanistic thinking.

<table>
<thead>
<tr>
<th>Edith</th>
<th>When we first started working on it, we were trying to make our cardboard prototype and make it two stories and have a cardboard stuck underneath it and having it taped and go like this to show a lot of flowing and going back under the mantle. Well we unfortunately changed our minds when we heard one of our group members talk about LED lights and how we can have them pop up when the plate goes underneath them so we decided to go with that.</th>
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Episode 72
Taken together, student attendance to nature of account in the Earth Science 3 unit fails to match the co-constructed classroom meaning that prioritized mechanistic thinking. While about half the students were able to provide more sophisticated accounts of the phenomenon (a reasonable expectation for the final model), the other half seemed to flounder in the unpacking of the account. Many students from both groups tended to focus on the physical representation of the final duct tape model, which likely overshadowed their attendance to the nature of account. Overall, this suggests that the co-constructed classroom meaning was not applied as students built and discussed their final models. Instead, it is possible that Mrs. L’s engineering emphasis was used as applied meaning as students engaged in the final model.

Summary of Findings

As Mrs. L and the students engaged in practices in the classroom discourse, they co-constructed meaning that was authentic to both the discipline of science and to students. Not only was Mrs. L supporting students in developing a framework that linked the goal of convincing with the need to include evidence, she was also prioritizing sophisticated attendance to justification and mechanistic thinking. The students in turn were buying into Mrs. L’s framework as they provided unprompted justification of ideas, attempted to unpack novel phenomena, and exercised student agentive voice in the classroom during these activities. I argue that this co-constructed meaning was especially rich given that these patterns were evident in the first three lessons of
the unit; to continue in these patterns of discourse would be to develop a rich and epistemologically meaningful framework for engagement in the practices.

In my driving research question, I asked if this meaningful engagement in the practices was sustained as students constructed and discussed their final models. Based on the student interview data, there was no evidence that this meaningfulness continued to the construction of the final models (Figure 15). Students bought into the low-level goal of informing and then constructed their models accordingly. Students frequently reported not using evidence in the construction of their model, and when evidence was used, students failed to reason about the connection to the claim. Furthermore, the most commonly cited source (simulations from class) suggested that the activities Mrs. L used to replace the practice-based engagement were rote in nature. Many students were not foregrounding the mechanistic unpacking of the phenomenon, instead focusing on the engineering feats needed to animate their models. Together, this suggests that the co-constructed classroom meaning was undoubtedly abandoned as students constructed and thought about their final models.

The Earth Science 3 unit was unique both in final knowledge product and teacher approach to the unit. While I cannot definitively argue that the changes Mrs. L made to the unit or to the framing of the final model resulted in the patterns we see in the student interviews, I believe that the explanation lies somewhere in the blank space between our last classroom taping day in Lesson 1-3 and the interviews in which students talk about their completed (or almost-completed) models. I unpack several possibilities and implications in the next
chapter. Regardless, based on the discrepancies between the patterns in the classroom discourse and the student interviews, I argue that Mrs. L did not support students meaningful modeling engagement across the entire Earth Science 3 unit.
Chapter 6: Overarching Patterns

Summary of findings across three units

To answer my research question (How did the teacher support students across a modeling curriculum?), I broke the data into two halves: *How did Mrs. L and the students work together to co-construct meaning in the classroom?* and *How did the students apply that co-constructed meaning to their final models?*

The goal here was to see if Mrs. L had supported the students in engagement in meaningful modeling during the class time and then see if students bought into that framework of meaningfulness as they constructed models on their own. If Mrs. L supported the students across the entire unit, I would expect to see authentic engagement in models both in the classroom and as students discussed their final models based on student attendance to epistemic considerations. Of the three units I analyzed here, only the Earth Science 2 unit resembled sustained meaningfulness across the entire unit; in both Biology 2 and Earth Science 3, meaningfulness was abandoned in the construction of the final model and replaced with more rote completion of the task. In this chapter, I unpack several overarching themes that likely contributed to the patterns in data I showed earlier. Ultimately, this leads to the larger question regarding supporting students in meaningful practice engagement: *Is there room for product-driven*...
final models in a science classroom? To accomplish this, I first answer my research questions.

RQa. How does the teacher engage with the students in the classroom to co-construct meaning? This research question focuses on the ways the teacher and students interact to leverage a prioritization of epistemic considerations as students engage in a practice and construct meaning around that engagement. Figure 21 represents the data I shared in Chapters 3, 4, and 5 in terms of co-construction and application of meaning. In this section, I consider the kinds of discourse moves Mrs. L made to achieve co-construction of personally and scientifically relevant meaning with her students in the classroom as well as other factors that might have contributed to the success of students as they engaged in the practice.
Curricular context. One of the most basic ways in which Mrs. L supported her students in co-construction of meaning was through the use of the IQWST curriculum. Although the challenges of authentic implementation of curricula are well documented (Abd-El-Khalick & Akerson, 2004; Crawford, 1999; Davis, Petish, & Smithey, 2006; Duschl & Gitomer, 1997), with the help of extensive teacher educative materials and guides, engagement that aligns with NGSS is possible (Crawford, Kelly, & Brown, 1999; Lizotte, McNeill, & Krajcik, 2004; McNeill & Krajcik, 2008). The IQWST curriculum has a history of success.

Figure 21. Comparison of engagement in practices across three units.
in foregrounding practice engagement (Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008), and Mrs. L is quite familiar with the context. While I do not explicitly address curricula in my research questions as a factor in co-construction of meaning, I bring it up now because it is possible this resource helped Mrs. L in engaging with the students in the classroom to co-construct meaning.

As evident in Figure 21, sophisticated and frequent attendance to the epistemic considerations was prevalent in classroom discourse in each of the three units. The days in which I collected and analyzed data in the classroom were aligned with specific lessons in the IQWST curriculum, and Mrs. L followed many of the supports presented in the teacher resource book; ergo this data supports other studies that suggest curricular context aids in scaffolding meaningful practice engagement (Berland & McNeill, 2010; Davis & Krajcik, 2005). This is not to say that curriculum alone can produce the kinds of meaningful engagement I presented within this dissertation; Mrs. L made specific discourse moves that prioritized epistemic thinking and student epistemic agency. Here, I merely indicate that a complete analysis of the data should include IQWST curricular context as a potential contributor to the overall co-construction of meaning in classroom discourse.

**Attendance to epistemic considerations.** Mrs. L’s attendance to the epistemic considerations in the classroom discourse likely played a key role in classroom co-construction of meaning that prioritized epistemic thinking. In each of the units, Mrs. L attended to the epistemic considerations in ways that
suggested their importance in the practice, and her attendance likely cultivated student attendance (Table 6). Table 6 outlines one specific way in which Mrs. L attended to each epistemic consideration in the three units. Although I have already unpacked each example in the respective unit chapters, I bring them up again now to exemplify how Mrs. L used attendance to the epistemic considerations as a means to cultivate their importance in the practice. For example, as Mrs. L pushed on the importance of identifying a target audience in the Earth Science 2 unit, students began to consider this aspect of their models and explanations more, which led to increased student attendance. As Mrs. L repeatedly brought up the idea of being convinced by evidence in the Earth Science 3 unit, students eventually sought out more evidence to justify their claims. Together, this negotiation of epistemic attendance led to the co-construction of meaning that prioritized certain considerations as students engaged in a practice.

Table 6

<table>
<thead>
<tr>
<th>Epistemic Consideration</th>
<th>Audience</th>
</tr>
</thead>
</table>
| Earth Science 2         | *And what you have to think about is like who’s the audience of this explanation? When you explain this this in your own words why temperature varies with latitude, who are you explaining this to?*
| Biology 2               | *So that’s an important point. Who is the audience? What, what are we assuming this person knows at this point in this, in this model. Is this model for a sixth grader who, like, if I were a sixth grader, I’d be like “bolus? What the heck is that”* |
Earth Science 3: I wanna be more convinced that they used to be part of the same sheet of paper.

Justification

…. because we’re trying to like convince ourselves, teach younger people, or prove to a university professor that we understand, but we need, regardless who our audience is, we need to make sure we have evidence so we’re convincing.

Earth Science 2: What else have we done to try to explain how osmosis works?

Biology 2: So if we’re gonna claim that these continents used to be together, we have evidence besides the fact that they just look like thee fit. Did that-is that convincing enough?

Nature of Account

Earth Science 2: I still wanna know why do some places up here get lower intensity light. The light is not hitting it perpendicularly, whereas this gets light coming at a perpendicular angle.

Biology 2: What part of this is how and what part of this is why?

Earth Science 3: They are colliding in some places. Um, are they colliding in Oklahoma? Is Ohio, Oklahoma? In order to collide, they have to be two plates touching each other, right? Is-are there two plates meet in Oklahoma?

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**Negotiation of Student Agency.** Another way Mrs. L supported co-construction of meaning in the classroom was by supporting student epistemic agency. In each of the unit chapters, I provided examples that show how Mrs. L allowed classroom space for students to exercise their agentive voice in terms of building knowledge and attending to epistemic considerations. Mrs. L did this by seeking student ideas without evaluating those ideas, providing space for peer to peer interactions during knowledge construction, and acknowledging student cognitive contributions. Students responded in turn by attending to the epistemic
considerations unprompted (and in sophisticated ways), asking questions that suggest higher cognitive thinking, and collaborating to make sense of ideas. This cooperation in negotiating epistemic authority allowed for Mrs. L to support students in the co-construction of meaning that values student as agents of epistemic thinking.

**RQb. How do students apply the co-constructed meaning to the knowledge product?** As I share in Figure 21, students applied the co-constructed meaning to their final models in only the Earth Science 2 unit, abandoning the meaningfulness co-constructed in the Biology 2 and Earth Science 3 classrooms for a more procedural approach to the knowledge products. The data I presented in each of the unit chapters indicates that students shifted their framing of the epistemic considerations to less sophisticated engagement as they discussed their final models in Biology 2 and Earth Science 3. Based on the data I shared, students are not applying the co-constructed meaning to their knowledge products in those units, which further suggests that the answer to my overall research question is that the teacher does not support students in across the entire modeling curriculum in those two units. With this in mind, the next question is: Why did we see sustained meaningfulness across the entirety of Earth Science 2 but not Biology 2 or Earth Science 3?

While I cannot definitively provide an answer to this question, or make claims regarding causality, in the next section I will suggest potential factors that may have contributed to the discrepancies in meaningfulness across units.
A discussion regarding patterns in meaningfulness across units.

There are a variety of factors that might influence students to abandon the co-constructed classroom meaning as they build their final models. Students have unique backgrounds, personalities, and interests, and at any given time they are experiencing a diverse array of external forces acting on them. With this in mind, it is virtually impossible to control for variables in human subjects in a classroom setting. The patterns of epistemic attendance that I shared in the unit chapters are not anomalies; Mrs. L and the students repeatedly engaged in discourse that suggested co-construction of meaningfulness and the students consistently attended to those epistemic considerations in the aforementioned patterns in their final interviews. Although highly unlikely, it is possible that the interview students experienced external forces (home life, stress in a different class, a current event, a change in lunch schedule) that influenced their responses in the interviews to reflect rote attendance to the epistemic considerations as they discussed their final models. Because we interviewed 18 students over the timespan of several consecutive weekdays following the end of the unit and the student responses consistently followed the patterns I shared previously, I find the scenario that exaggerates external factors to be unrealistic.

Based on previous literature and the nature of my findings, a plausible explanation for the shifts in student application of meaning to their final models is that students were responding to shifts in Mrs. L’s framing of the final knowledge product. We are aware that Mrs. L had alternative goals for the knowledge products at the end of the Biology 2 and Earth Science 3 units based on the
changes she made to the units and through personal correspondence. At the time the data were collected, these goals were of little concern to the overarching research questions of the study and were therefore not recorded in minutiae. Additionally, because the original data collection plan hinged on engagement in practices as dictated in the IQWST curriculum, the days in which Mrs. L changed or removed those practices were considered to be irrelevant and thus not recorded. In hindsight, a record of these happenings would have been instrumental in cementing the case I make for the importance of consistently meaningful approaches to final models. Regardless, there are still patterns in the data that suggest the ways in which Mrs. L approached the final models influenced the ways in which students engaged with those final models. I am not claiming causality here; I am merely speculating about potential reasons for what appears to be a shift in Mrs. L’s support for students as they construct and discuss their final models. In the next section, I will be expounding on the patterns that suggest a shift in modeling approach influenced the meaningfulness of modeling engagement.

**How a product-centered approach to modeling removes meaning**

One of the most obvious trends in the data I have presented here is consistent (and yet varied in content) co-construction of meaningfulness in classroom discourse and the obvious departure from that meaning in the final models of two of those units. I represent this in Figure 21 using the shaded boxes on the left to indicate engagement in scientific practices in the classroom. Each of these three units was characterized by co-construction of meaning in the
classroom that included aspects of both scientific and personal relevance; here, I indicate this with patterned shading. By using different patterns for each unit, I am representing that while the classroom engagement in each unit aligned with our understanding of meaningfulness, the nature of that meaning was quite variable from unit to unit. For example, Mrs. L and the students foregrounded nature of account much more explicitly in the Biology 2 unit, but favored attendance to audience in the Earth Science 2 unit. There are many ways that meaningfulness can be co-constructed in classrooms; this study helps to characterize several such ways.

The boxes on the right represent the students’ engagement with the final models in each of the units (Figure 21). In Earth Science 2, very few modifications were made to the original curricular approach to the final model, which was intended to be a continuation of the models and explanations students had been building in class. This approach aligns with authentic practice engagement in that the construction of the “final” knowledge product is the result of many iterations of knowledge products based on data collection and analysis, revision, evaluation, and application to new situations (Schwarz et al., 2009). The “finality” of the knowledge product lies not within the completion of a satisfactory product, but in the product’s ability to answer the driving question and with the understanding that science is an iterative process and thus the model may change in the future with continued use. Because the data from the Earth Science 2 classroom discourse and student interviews suggests that this particular approach to the final seasons model was implemented (which I will
discuss in subsequent sections), I represent the continuation of modeling across the entire unit with an arrow moving from the Earth Science 2 classroom box to the Earth Science 2 final model box (Figure 21). These boxes share the same pattern because the applied meaning reflected the co-constructed meaning, which was authentic in both situations.

In both the Biology 2 and the Earth Science 3 units, meaningfulness was co-constructed in the classroom discourse as Mrs. L and the students were engaged in practices (Figure 21). Again, the meaning that was co-constructed by the group in each setting was unique yet still reflected authentic practice engagement, which I represent here by the patterned boxes on the left. In both of those two units Mrs. L approached the final model in ways that indicated her buy-in with regard to modeling, but also indicated her focus was on the product of the model rather than the cognitive and iterative aspects of the practice. As a result, the students approached the final models in those two units in ways that did not reflect the co-constructed classroom meaningfulness; rather, the students approached those models in ways that reflected a focus that was shifted from the cognitive process to the physical product. I represent this using the gray boxes to the right of the Biology 2 and Earth Science 3 boxes; the lack of pattern continuity reflects the lack of application of the co-constructed meaning to the final model by students (Figure 21).

While I cannot claim that the changes Mrs. L made to the final models directly influenced students to shift their attendance to more procedural enactment, I argue here that aspects of Mrs. L’s approach to the final models
align with the application of less sophisticated meaning seen in student interviews, which ultimately reflects a shift in focus from cognitive process to physical product. Compared to the quality of attendance to the epistemic considerations in the classroom discourse by Mrs. L, the ways in which she modified the units and final knowledge products are less scientifically and personally meaningful. For example, by shifting the focus of the Biology 2 knowledge product from the models students had been creating in class to an infographic that was separate from the class engagement, Mrs. L may be detracting from the kinds of knowledge construction and cognitive agency that should be involved in a practice. In addition, by removing the practice engagement from the Earth Science 3 unit in exchange for more time spent on perfecting the duct tape model products, Mrs. L may be taking away opportunities for high quality scientific practice classroom engagement in the modeling process. Together, the patterns in the student interviews suggest that even accounting for the gaps in data between the last classroom data collection day and the student interviews, Mrs. L’s modifications to the final models in the last two units resulted in shifted focus from practice engagement to rote completion of a final product. I now move to describing these patterns and making suggestions as to the overall trends in how Mrs. L supported (or failed to support) the students across the modeling curriculum.

**Approach to final models influence attendance to audience.** One of the most obvious shifts in student application of meaning comes in terms of the audience epistemic consideration. In the Earth Science 2 unit, the data indicate
that students likely applied the co-constructed classroom meaning to their final models (as reviewed in Chapter 3). This argument is based off the fact that the classroom co-constructed meaning prioritized sensemaking and informing goals for engagement in practices, and students tended to reference these two goals frequently as they discussed their final models in the interviews. This connection between audience attendance in the classroom and audience attendance in the final models suggests that the approach to the final model in Earth Science 2 served as a continuation of the meaningful practice engagement from the classroom discourse. The Earth Science 2 final model was the result of continuous knowledge construction up to that point.

We see this more clearly in Figure 22, which shows the most commonly cited audiences in the student interviews compared to Mrs. L’s intent for those models based on our understanding of her design modifications, descriptions in the classroom, and personal correspondence. For example, when the final model was presented as a way for students to gather thoughts about the phenomenon and represent it in their own way, just as students had been figuring out the entire unit, the students believed that the audience was still closely related to the classroom community (Figure 22). In this particular unit, students frequently identified their audience first as the class community and themselves, then cited younger students or anyone. To our knowledge, Mrs. L did not provide any further scaffolding for the Earth Science 2 model in terms of audience. This suggests that in the absence of decisive parameters on student knowledge products, or rather, in the presence of continued support for the practice as a
continuation of classroom practice engagement, the students will continue to find personal relevance in the model as an audience.

The connection between audience attendance in the classroom and student attendance to audience in the final models became unhinged in the Biology 2 and Earth Science 3 units, which suggests that students were not engaged in sustained meaningful practice engagement. In examining the shifts in audience attendance across these units and Mrs. L’s goals for the final models in the Biology 2 and Earth Science 2 units, we see that student responses tended to match Mrs. L’s final model intent more closely than they reflected the co-constructed classroom attendance to audience. These shifts in audience attendance reflect the larger shift in approach to modeling from one that values the cognitive process to one that values a displayable product.

When Mrs. L presented a target audience for the final knowledge product, students bought into that idea, which we can observe based on the trends from the Biology 2 and Earth Science 3 units (Figure 22). In the Biology 2 and Earth Science 3 units, students had a relatively clear perception that their audience was a specific “other,” but could be extended to “anyone” who wanted to learn. With regard to the “other” category, students gave responses that closely aligned to the audience intended by Mrs. L, suggesting that students readily adopted teacher approach to these activities (Figure 22).

I find it important to mention that the frequency with which students identified the “teacher” as a member of their target audience might indicate rote participation in the activity (Figure 22). As I discussed in Chapter 4, Elliot
indirectly cited Mrs. L as an important audience in the construction of his body systems infographic. In Elliot’s interview, he recounted several aspects of his infographic that were influenced by the rubric or the deadline for the project, thus indicating that his engagement in the construction of the infographic was more reflective of procedural enactment. We understand that Mrs. L likely did not intend for the audience of these knowledge products to include herself; this trend in student ideas about audience could be attributed to teacher attendance to evaluation measures, which is frequently done as a way to assess product completion, but is much more nuanced in terms of assessing cognitive engagement in a practice. Nonetheless, this further supports the idea that students pick up on shifts in modeling approaches from process-driven to product-driven, whether intentional or not, and frequently apply this meaning to their knowledge products.
Earth Science 2
A model to explain seasons (based on 3-D model from class)

Biology 2
An infographic for science night

Earth Science 3
A duct tape model to send to other 8th graders
Figure 22. Final model approach for each unit along with who students perceived their audience to be. All coding categories are shown for each unit (circles). Shaded circles represent the most frequently coded categories.

Although who students thought their models were for was reflective of the shifted approaches to these models, much more critically so were students’ ideas about the goals for said models. Compared to the co-constructed classroom meaning, students’ applied meaning for Biology 2 and Earth Science 3 final models were much more rote, which I argue stems from shifts in attendance to audience as a result of approaching the final model as a displayable product. When the final model is approached as part of the progression of knowledge construction in a practice sustained across a unit, the students’ perceptions of the model’s purpose are much more salient in terms of sophistication.

Figure 23. Attendance to Audience in Earth Science 2 classroom discourse and final model.

For example, the classroom meaning in the Earth Science 2 unit was co-constructed based on attendance to the purpose of practice engagement as to inform and to make sense of ideas (Figure 23). Because the approach to the final model was a natural continuation of the classroom engagement in practices, students also saw their final models as primarily serving similar purposes (Figure 23). As I unpacked in
Chapter 3, there were a variety of other stated purposes in addition to informing and sensemaking with the final models. These additional purposes do not detract from the meaningfulness; because students had the freedom, and thus epistemic agency, to view the final models as a continuation of the practice of modeling, they were also able to imagine a variety of sophisticated purposes for their knowledge products. As is the case in the other two units, when the focus of the final model becomes an embellished physical product for sharing or displaying, this creative aspect of the practice is overshadowed by more procedural goals.

![Diagram](image)

*Figure 24.* Attendance to Audience in Biology 2 classroom discourse and final model.

When Mrs. L approached the Biology 2 final model as an infographic for science night, she shifted the focus of the modeling task from more sophisticated sensemaking to exclusively low-level informing (Figure 24). In doing this, she interrupted the flow of meaningful practice engagement in the classroom discourse and essentially asked students to construct a new model without the social and cognitive engagement from the classroom. Recall that near the beginning of the unit, Mrs. L explained
to students that they would be working in several subject areas (wellness and fitness, science and stem foundations) to construct a final model for the Biology unit, and at first glance, this seems to be a productive and collaborative move meant to support students in a comprehensive modeling practice. Additionally, Mrs. L mentioned that she modified the unit to support the construction of this knowledge product by building in “models every step of the way so you are documenting the big ideas that you've learned.” Again, this may reinforce the iterative process of modeling, but together with her implicit and explicit goals for the model, these actions appear more like procedural pathways to achieving a high-end product. For example, Mrs. L reminds students of the “big picture: making an infographic at the bottom of your calendar to explain how metabolism works;” the goal of explaining using an infographic is relatively low-level compared to the sensemaking Mrs. L and the students spent much of their time on in class. Furthermore, while modeling indicates a scientific practice and the social and cognitive aspects that accompany it, making an infographic does not. Finally, when she tells the students, “I really want you to take these models seriously,” and warns them to not procrastinate, Mrs. L is removing the authenticity from the practice and treating this as a school task done for very low-level purposes epistemologically speaking. As I have shown in the interview data in Chapter 6, students respond accordingly and overall fail to frame their models as having a purpose more sophisticated than informing.
Similar patterns occur in the Earth Science 3 unit. Despite the strong attendance to audience goals as sensemaking and persuasion in the classroom co-construction of meaning, students did not identify these goals as they discussed their final models (Figure 25). The modifications Mrs. L made to this unit specifically downplayed the role of practice engagement and replaced those kinds of activities with more time for students to construct their final duct tape models. Thus, rather than engage in the practice of modeling continuously throughout the unit, the data suggest that the focus shifted to product completion when students began to work on their final models.

Figure 25. Attendance to Audience in Earth Science 3 classroom discourse and final model.

A clear purpose can be a uniting factor for students as they work together to construct a knowledge product in the classroom. As students draw upon the collaborative and iterative aspects of scientific practices, a refined attendance to audience can direct students in making other epistemic decisions as they build a model. When the final model becomes a separate entity from the knowledge construction in the classroom practice, as is evident in the varied audience goals in the Biology 2 and
Earth Science 3 units, the final models lose authenticity. When the final model is the continuation of meaningfulness co-constructed in the classroom and bears similar goals, as we see in Earth Science 2, the practice aspect of modeling is upheld in the product. As teachers consider how to support meaningful engagement in the practice throughout an entire unit, they must find ways to connect the purpose of the final model to the sophisticated purposes of practice engagement in the classroom discourse.

**Attendance to epistemic audience goals situates the need to justify.** Continuity of purpose in knowledge product construction is critical in supporting sustained epistemic engagement from beginning of unit to the final model; establishing engagement in sophisticated purposes is essential to leveraging similarly sophisticated attendance to the other epistemic considerations, specifically justification. Why students are building a model, and to some extent, who will be using the model, influences the epistemic choices students make as they figure out how best to meet the needs of that audience and purpose. Students who aim only to demonstrate or inform an audience might not see the need to justify the ideas within the model, but rather provide a detailed account of the phenomenon. Conversely, a student intent on convincing an audience would need to prioritize evidence and reason about it in such a way that supports their claim to that specific audience. We see this play out in a meaningful way in the classroom discourse, but in rote ways as students reflect upon their Biology 2 and Earth Science 3 final models.
When Mrs. L and the students attended to audience and justification together in the classroom discourse, it occurred in a way that supports the claim that these two epistemic considerations are linked. For example, in the Earth Science 2 unit, Mrs. L asked her students, “Were we looking at the moon phases to try to figure out why some places are hotter than others? No,” which links engagement with data as a means to make sense of ideas. This rhetorical question positioned the purpose of practice engagement as classroom sensemaking (thus satisfying attendance to audience in terms of both who and why), and referenced a fictitious data-gathering activity that prioritizes the need for data in justifying ideas (thus satisfying attendance to justification in terms of hypothetical source and implied reasoning). In this particular utterance in the Earth Science 2 classroom, the teacher was not only prioritizing the two epistemic considerations of audience and justification, but she was attending to them jointly, linking them in a way that leverages the need to construct knowledge. Later in this unit, students picked up on this prioritization and suggested they add evidence to their class consensus explanation because as Howard states, “If we don’t have any evidence how is someone gonna know that they can rely on this information?” Again, we see how both Mrs. L and the students found value in using justification of a source as a means to either make sense or persuade using a model or explanation.

The two examples I shared came from the Earth Science 2 unit, which occurred at the very beginning of the students’ eighth grade year, which suggests that even at the start of the year, Mrs. L and the students were able to see a
connection between sophisticated purposes of practice engagement and the inherent necessity of justification in those situations. As I discussed in Chapters 4 and 5, this link was sustained in the classroom discourse in the Biology 2 and Earth Science 3 units as well: when students were constructing or using a knowledge product to convince or make sense of ideas, they tended to spontaneously bring up evidence as a means to justify their ideas. Recall that the classroom discourse was reflective of co-constructed meaningfulness that prioritized sophisticated attendance to all of the epistemic considerations and that students were engaged (at least on the days in which we visited the classroom to videotape) in knowledge construction foregrounded in a practice. The engagement in a practice was problematized at the beginning of the unit via a driving question and students spent the remainder of the class time constructing knowledge to explain the driving question, and it seems as though this type of engagement was either explicitly or implicitly framed in terms of either sensemaking or persuasion for the class community or unspecified others. Also recall that rather than keep the final diagrammatic model or written explanation that was built into the unit as a natural progression of knowledge construction based on practice engagement, Mrs. L modified the Biology 2 and Earth Science 3 final models to focus on more traditional school goals. With shifted attendance to audience as a result of Mrs. L’s modifications, it comes as no surprise that students’ reflections of their final models in these two units tended to reflect lower-level justification.
When the goal of the Biology 2 and Earth Science 3 final models were modified to focus more on a product to demonstrate or inform, students often failed to provide evidence as support for their knowledge construction. In the Biology 2 unit, students nearly exclusively considered the goal of their infographic to be for informing or demonstrating, and an alarming number of those interview students also initially admitted they did not use evidence to construct their infographic (reviewed in Chapter 4). Leanne revealed that she did not include evidence in her infographic because she and her partner “were focused more on the storyline and making it more explanatory and more reasoning and claim than evidence,” which further indicates that these students were abandoning attendance to justification in response to shifted audience goals. When the purpose of a knowledge product shifts from constructing knowledge to telling a story, students respond accordingly and only include features salient to the rote goal. Similarly, students recalled in the Earth Science 3 unit that either they used no evidence to construct their models or the evidence they used came from models and simulations from authoritative sources (Percy’s recollection that they “looked at a lot of digital animations in class” (Episode 66)). While we would not necessarily discount the contribution of evidence from authoritative sources, I find it important to note that there is a clear difference in using models and simulations to make sense of puzzling ideas and using models and simulations to find the best way to create a 3-dimensional version of that phenomenon. One is a representation of phenomena that requires no reasoning on the part of the student (and thus is not considered “evidence”) and the other is a representation...
used by students for explicit reasoning on the part of the student as they make sense of ideas (Passmore et al., 2014). By removing the need for sensemaking and persuasion as valid purposes for the Earth Science 3 model, the students are not positioned to effectively reason about evidence in sophisticated ways.

When the attendance to audience is appropriately situating students in cognitively demanding knowledge construction scenarios, the need to justify is maintained. We see this happening in the Earth Science 2 unit, which I argued was a continuation of the co-constructed classroom meaningfulness because the knowledge product was a natural continuation of the knowledge construction from class. Recall from Chapter 3 that students held various ideas about who their audience was and why they were constructing the model in the Earth Science 2 unit, but that for the most part, the students were personally invested in the who and why. As such, and because there was still a strong connection between the final model and knowledge students had been constructing across the unit, students were better positioned to justify their ideas based on the evidence they had collected. Again, this is suggesting that by shifting the final model from knowledge students had been building as part of scientific practices in the classroom to a product that satisfies “school” goals, students will abandon the co-constructed classroom meaningfulness.

One of the most critical takeaways from the patterns in the attendance to audience and justification in both the classroom and the final model reflections is that these two epistemic considerations are closely linked. Audience influences the need for justification when students are building arguments (Berland &
Hammer, 2012). We see here that the same is true when students are constructing other kinds knowledge products; moreover, in this study I have provided evidence that suggests low-level attendance to audience results in similarly low-level attendance to justification. The classroom co-constructed meaningfulness in each of the three units suggests that both Mrs. L and the curricular context supported sophisticated attendance to audience which then pushed for more complex attendance to justification as students were engaged in a scientific practice. With appropriate scaffolds, students can become more sophisticated in their attendance to each of the epistemic considerations, which I expected to see as students progressed over the course of the year, specifically in terms of their final models. Because Mrs. L modified the final models in Biology 2 and Earth Science 3 to reflect more procedural “school” goals, student attendance to audience and justification in the interviews similarly represented rote enactment of the task. As teachers consider how to approach final models, the data here suggest that students justify when there is an established need (based on audience) and when they have been supported in understanding how to justify in the classroom during co-construction of meaning; eliminating either of these aspects results in rote attendance to the epistemic consideration of justification and thus rote engagement in the practice.

Mechanistic reasoning is not inevitable at the end of the unit. In each of the units I described earlier, there was a strong mechanistic focus in the classroom discourse, which indicated that the classroom co-construction of meaning prioritized attendance to the epistemic consideration of nature of
account. As I unpacked the reflective interview data, this prioritization was noticeably missing in the Biology 2 and Earth Science 3 units. Again, this suggests that students were not meaningfully engaged in the final models in those two units despite co-constructing meaning in the classroom that was both personally and scientifically authentic. This pattern in the data is somewhat surprising given what we know about the content-driven nature of many traditional classrooms - and even teacher ideas about what counts as science literacy and content knowledge (DeBoer, 2000; Lederman, 1999; Magnusson et al., 1999).

Of the various epistemic considerations, attendance to nature of account is arguably the most likely to be present in sophisticated levels at the end of a unit. At the beginning of a learning set, students generally hold very basic conceptions or even misconceptions of a given science idea; at the end of the learning set, students should have a much more complete understanding of that big idea. Granted, in traditional classrooms, student reasoning about the phenomenon may not reflect the upper anchors of the range of student ideas, but of the three epistemic considerations I have detailed in this dissertation, nature of account is the most likely to foregrounded by teachers and students. I make this claim with the assumption that many teachers are generally interested in content coverage and this particular epistemic consideration aligns most closely with those goals (Aguirre, Haggerty, & Linder, 1990; Van Driel et al., 2001).

Interestingly, despite an experienced teacher, a practices-driven curriculum, and a supportive, inquiry based school setting, we did not see
consistent sophisticated attendance to nature of account at the end of all the
units studied. Ideally, at the end of a unit that foregrounds mechanistic thinking
and sophisticated engagement in the practices, I would expect students to
become better at providing complete accounts of the phenomenon; however, this
happened in only one unit. Additionally, in all three units, Mrs. L and the students
co-constructed meaning that prioritized attendance to mechanistic reasoning. I
believe the key to understanding why student attendance to nature of account
was less sophisticated in the Biology 2 and Earth Science 3 reflective interviews
rests in the modifications Mrs. L made to the final models.

As I argued earlier, the focus on the final model as a product to be
disseminated influenced how the students attended to the epistemic
considerations of audience and justification; the same seems to be true, at least
in part, for attendance to nature of account. In the Biology 2 unit, recall that Mrs.
L modified the lessons to include more modeling. She shared this information
with the students, and at the surface, this indicates that Mrs. L finds value in
constructing and revising models throughout science learning. Upon closer
inspection, it seems as though these additional models may have been more
procedural in focus. In Chapter 4, Mrs. L warned students “to take these models
seriously,” and not procrastinate, which removes much of the authenticity of
engagement in modeling as a knowledge construction endeavor and reframes
the modeling as an activity to complete before it becomes “too much to do and
too little time.” Although the classroom discourse did not reveal that the co-
constructed meaning as a result of practice engagement was anything short of
authentic, student reflection on their final models indicated a more procedural focus.

In the Biology 2 unit, about half of the students failed to provide even nominally sophisticated attendance to nature of account as they explained their models. Consider Sam’s response in episode 73. In his response, Sam was only able to name one factor involved in explaining the phenomenon despite additional probing by the interviewer. Most of Sam’s descriptions were not about explaining the phenomenon but rather about how his travel brochure will look. We saw similar responses in the students who attended to nature of account at comparatively low levels.

<table>
<thead>
<tr>
<th>Interviewer</th>
<th>So what question are you trying to answer with your model here?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sam</td>
<td>How and why the body uses food.</td>
</tr>
<tr>
<td>Interviewer</td>
<td>Ok. Can you tell me a little bit more about how your model answers that question?</td>
</tr>
<tr>
<td>Sam</td>
<td>Well, we planned on putting, like- we planned on divided it into a travel brochure and having a cover and then when you open it, like this is going to be the digestive system, but then this is going to be all the information on how the body uses the food and then what each system does.</td>
</tr>
<tr>
<td>Interviewer</td>
<td>So can you tell me a little bit about what's -what you put in each section there?</td>
</tr>
<tr>
<td>Sam</td>
<td>Here on each part of the model- on each system that we learned, we took a picture out of a book and we traced it on tracing paper. So then we just could scan it into here to help show what is part of each system. And then on the bottom below the picture, we’re going to have information on what the system does to the food.</td>
</tr>
</tbody>
</table>

Episode 73
While half the students attended to nature of account in ways similar to Sam, the other half were able to reason about the factors involved in explaining the phenomenon, but only two students provided complete mechanistic accounts. Even the students who attended to nature of account in more sophisticated ways were very committed to the creative aspects of their models. When we asked students to tell us about their models (which generally elicits attendance to the account of the phenomenon in their model), these students tended to include responses that highlighted the product rather than the knowledge construction. For example, Violet, who named two factors and unpacked one, and her partner were making their model into a science video that would be “very interesting….fun, but also teach you stuff,” and Leanne, with attendance patterns very similar to Violet, focused on the aspects of her model that were salient to her “storybook” product. Alfred, one of the two students to provide a complete mechanistic account of the phenomenon, reflected that he made decisions based on things that would make his teacher happy (Episode 74). This particular episode is reminiscent of Mrs. L’s warnings to not procrastinate, which further suggests that students focused more on the product aspect of the final model than the process of knowledge construction in the Biology 2 final models.

<table>
<thead>
<tr>
<th>Alfred</th>
<th>I was gonna add [the large intestines], but then she said it wasn't important because we didn't -like, we were just showing how our cells use it….</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewer</td>
<td>Do you agree with your teacher that you shouldn't have included it?</td>
</tr>
</tbody>
</table>
Alfred  Well, I was kind of close on time, so at the end I kind of liked it but it wasn't important to the grade. It just would have been extra work.

Episode 74

We find similar patterns in the Earth Science 3 unit, although more students are able to reason about the phenomenon at higher levels than in the Biology 2 unit. Still the attention to the final models as products rather than as representations of constructed knowledge positions students not as cognitive agents of the representation in an authentic practice, but rather as students completing an assignment. For example, as Lindsay was explaining how her model explains volcano formation, she included information about the mechanics of the duct tape model as well (Episode 75).

Lindsay  Okay, so in our model, Japan is an oceanic, oceanic plate type, and so one oceanic plate.... this is plate one and plate two is going under the other one. And so in our model we're showing the subducting plate moving downward by a crank and whenever you twist the crank it pulls inward...

Episode 75

Edith described the changes she made to her model, which focused on mechanical modifications rather than the ways her thinking about plate tectonics had changed (Episode 76), as did Kelly (Episode 77).

Edith  When we first started working on it, we were trying to make our cardboard prototype and make it two stories and have a cardboard stuck underneath it and having it taped and go like this to show a lot of flowing and going back under the mantle.

Episode 76
Kelly

Well, originally we weren't going to have handles or anything - we never did finish our prototype, but... we were originally just going to do something similar that the other mid-Atlantic ridge people have done in the past. We weren't going to have the rolls pop up, we were just going to have just where you have the plates on top and you can just pull them apart basically, but we thought that was too similar to what other groups have done in the past.

Episode 77

Together, these examples further highlight how Mrs. L's focus on the duct tape model assignment became more foregrounded than the classroom co-constructed prioritization of mechanistic thinking.

Summary of Patterns

Although there were patterns of meaningfulness within each unit that I have described thus far, in this chapter I have shared the larger finding regarding approaches to final models. As shown in Figure 21, Mrs. L supported meaningful engagement in the practices in the classroom discourse in each of the units as evident in the ways she and the students attended to the epistemic considerations and negotiated epistemic roles. Not only did the students and teacher engage in the practices in ways that were authentic to the discipline of science via epistemic thinking, but they also did so in ways that suggested that these ideas were personally relevant to the classroom community. Conversely, this meaningfulness was abandoned in the Biology 2 unit and the Earth Science 3 units when students were engaged in the actions of the practice without the epistemological underpinnings of those actions (Figure 21). Additionally, students reported constructing their models with little commitment to the necessity of the final product, suggesting that personal relevance was absent from the
engagement in these units. Only in the Earth Science 2 unit did Mrs. L help students construct meaning that was both personally and scientifically authentic. Based on the data within and across units, the most successful case of well-supported engagement in co-constructed meaningfulness over the course of an entire unit occurred when the final model was a continuation of the knowledge students had been constructing in the classroom. The least successful approaches to the final model in terms of meaningfulness to students and to the discipline occurred when there was a gap between the classroom knowledge product construction and the product-driven final model wherein the focus was visual appeal rather than cognitive use of the model.
Chapter 7: Implications

Together, these conclusions point to the need to shift our approaches to modeling in the classroom—especially in terms of the idea of a final model. As I have argued thus far in this dissertation, modeling in the classroom can be an effective entry point for engaging students in the kinds of epistemic thinking that reflects authentic science. In this study, the authentic engagement was supported by the curriculum and the ways in which Mrs. L scaffolded the students as they worked together to co-construct meaning that prioritized the EIPs. The sophisticated attendance to epistemic considerations we saw in the classroom discourse is an example of possible meaningful practice engagement with appropriate scaffolds. Furthermore, the differences in the classroom discourse in all three units suggests that meaningfulness can take a variety of forms without losing authenticity. These findings are promising for teachers looking to achieve meaningful practice engagement in their classrooms, as the data suggest there are many “right” ways to engage students in scientific practices. Conversely, the data also suggest that there are various ways to miss the mark. Without a clear understanding of what makes a practice meaningful, there is a risk that the modeling activity can become rote, as we have seen in two of the units I presented. The findings I have shared can be used to guide the development of teachers’ ideas about how to approach modeling in the
classroom. Before I expound on these suggestions, I will first examine how Mrs. L’s modifications reflect common ideas about modeling.

**Current teacher understandings of scientific modeling**

The turn to practice-based approaches to science learning advocate the use of knowledge products as tools for thinking and constructing knowledge (Duschl & Grandy, 2013; Ford & Forman, 2006; Osborne, 2014). Is this really how the practice of modeling is approached in the classroom? In some cases, the answer is yes. There is a large body of literature purporting the ways in which knowledge product construction in the classroom is a valid and effective way to engage students in scientific thinking (Grosslight et al., 1991; Kenyon, Schwarz, & Hug, 2008; Schwarz & White, 2005; Schwarz et al., 2009; Von Glasersfeld, 1998). The data here contribute to this understanding. In many other cases, it becomes clear that shifting teacher views of models as products to scientific models as processes or thinking tools is an obstacle to meaningful implementation.

As I brought up earlier in this dissertation, scientific modeling is a challenging concept for science teachers because of the nuances of the use and cognitive frameworks surrounding scientific modeling (Abd-El-Khalick & Akerson, 2004; Crawford, 1999; Davis, Petish, & Smithey, 2006; Duschl & Gitomer, 1997). Although Next Generation Science Standards encourage the use of scientific practices in the classroom, there are few recommendations for how to accomplish this in the classroom and pre-service teachers are rarely prepared to design meaningful practice engagement (Abd-El-Khalick & Akerson, 2004;
Thus, it comes as no surprise that while the curriculum helped to scaffold Mrs. L’s practice engagement with her students in the classroom discourse, she shifted to less meaningful approaches to her redesigned final models. Other studies have found that teachers may hold paradoxical views about scientific practices; in some ways, teachers can have very sophisticated understandings of scientific models as representations or tools, and yet maintain their positivist ideas regarding the more materialistic aspects of the model (Yenilmez & Oztekin, 2016).

In my findings, we see that Mrs. L works with the students in the classroom to prioritize sophisticated epistemic considerations at the same time she prepares students for rote application of the practice in their final models. Although it is troubling to discover that even well-supported and experienced teachers have competing naive and sophisticated understandings of modeling, I believe my data have promising applications to further developing teachers’ conceptions of meaningful modeling in the classroom and beyond. Below, I discuss how my findings can be used to support teachers’ understandings of scientific modeling.

**The need to reframe teachers’ ideas about science**

To begin to solve the problem of rote experiences with classroom modeling, I believe we must first shift teachers’ ideas about finality in science. As I unpacked in Chapter 6, the shift from building models as visible tools in knowledge construction to building models for materialistic school goals was

Akerson, Morrison, & McDuffie, 2006; Van Driel, Beijaard, & Verloop, 2001).
reflected in the students’ shift from sophisticated epistemic consideration attendance to rote completion of a task. Unlike the traditional content-driven school approach to science as a body of facts, the turn to practices pushes engagement in science that is constructive and iterative (Duschl, 2008; Ford & Forman, 2006; Lehrer & Schauble, 2006; Osborne, 2014). This may be uncomfortable to teachers, especially those without science backgrounds, and challenging positivist pedagogies is a difficult task. Many professional development programs and other educative tools are already in place to support these shifts toward more constructivist science views (Thompson, Windschitl, & Braaten, 2013; Van Driel et al., 2001; Windschitl, Thompson, Braaten, & Stroupe, 2012), but it is imperative that scientific modeling be explicit within these scaffolds.

Because the use of ‘models’ in the classroom has classically been as rote tools of passive information transfer, teachers may have difficulty abandoning this use, as we have seen in the case of Mrs. L and the Biology 2 and Earth Science 3 units. Despite the literature to support the practice of modeling as a social and cognitive process of knowledge construction, teachers are not well-informed of these ideas and could easily revert to models as “representations of phenomena” rather than as “tools for making sense of phenomena” (Passmore et al., 2014). Despite Mrs. L’s use of models in the classroom as sensemaking tools, she still approached the final models as entities separate from the rich and constructive classroom endeavor, and her students responded accordingly. To better position teachers to support meaningful practice engagement in their
classrooms, we must continue to shift their conceptions about the separation between science and school science, and help teachers understand the constructivist approach to science.

The need to reconsider the application of knowledge products in the classroom

Along with the continuation of educating teachers on product approaches to science and science practices, there is a need for a more specific conversation regarding the role of knowledge products as summative assessments in the classroom. While we have seen successful examples of knowledge construction in the classroom using models both in this study and in others, there is a concern that diagrammatic models and written explanations can easily become ways for teachers to assess student learning across a unit, as I discovered in the Biology 2 and Earth Science 3 units. The findings I share in this dissertation can contribute to the larger dialogue of the tensions between supporting and assessing authentic science knowledge construction.

Are models effective forms of summative assessments?

Teachers experience a host of stressors; from engaging learners and designing lessons to complying with administration and experiencing their own evaluation, teachers are pulled in a variety of directions. Currently, teachers rely on evaluation of student work to satisfy several of these demands. My argument here is not to eliminate student assessments entirely, as it is neither a wise nor reasonable expectation. Based on my findings, I argue that we should strongly
reassess the use of knowledge products as a form of student summative evaluation.

In the Biology 2 unit, recall that as a class, students co-constructed meaning that reflected authentic practice engagement. While in class, the students exhibited sophisticated attendance to the epistemic considerations, which I have argued is precisely the kind of interactions we should aim to have in science classrooms. In assessment terms, as a whole, the students in this class were doing satisfactory to exemplary work. Further, recall that as a class, attendance to the epistemic considerations took a precipitous drop in sophistication when students discussed their final models. In general, students failed to justify ideas, were often unable to unpack the reasoning behind the phenomenon, and in some cases reported that the rubric rather than cognitive agency determined their modeling choices. In short, the students were doing highly unsatisfactory work in terms of authentic science. Despite students’ reflections that they could have focused more on evidence or been more explanatory, the students seemed to be excited about the infographics they were building, specifically citing “fun” or creative aspects of the products. The students did not seem to be disappointed in their infographics, which could also suggest that perhaps Mrs. L might also not be disappointed. Granted, I did not examine the contents of Mrs. L’s grading rubric, the scores students received on their infographics, or Mrs. L’s overall satisfaction with the student work after it had been graded (although this kind of future analysis might contribute to the larger discussion of assessing knowledge products). Ergo, it is quite possible that the
students failed to meet Mrs. L’s expectations for the infographics in the Biology 2 unit. Regardless, the question is not whether or not the final model was sufficient to pass muster at the end of the unit; the question is whether or not the final model reflected students’ abilities to think critically about the science knowledge they had been building thus far. In the case of the latter, I argue that it does not.

Although I have so far discussed the merits of using the infographic from the Biology 2 unit as an effective summative assessment of students’ scientific reasoning, I could have easily replaced the infographic with the duct tape model from the Earth Science 3 unit. In both cases, students co-constructed meaning in the classroom via authentic science discourse, yet were highly unproductive in representing science metaknowledge in discussing their final models. If the goal of practices in the classroom is to meaningful engage learners in the social and cognitive aspects of science and if the goal of summative assessments is to evaluate student proficiency in scientific understanding, using product-oriented final models as a means of assessment is a poor indicator of either.

Of course, that brings me to the Earth Science 2 unit in which the students applied the co-constructed classroom meaning to their final models. As a whole, students tended to use rich and relatively sophisticated epistemologies as they discussed their knowledge products, which would likely suggest that these students are doing satisfactory science learning. Again, if Mrs. L assessed these final knowledge products, she did not share her rubrics nor did she provide any commentary on how well she thought students did or did not learn in the unit based on the final model. Even if she had, would her evaluation of student
“learning” in the Earth Science 2 unit be comparable to our evaluation of student engagement in meaningful science? The use of backwards design in lesson development calls for teachers to scaffold the kind of improvements they want to see throughout the unit (Wiggins & McTighe, 2005). Would Mrs. L’s unit objectives have matched our own and thus would her evaluation of student work been similar? Based on her modifications to the Biology 2 and Earth Science 3 final models to reflect salient “school” activities, I do not think so; while the Earth Science 2 models were sophisticated in attendance to the epistemic considerations, they were not the colorful, entertaining products seen in the other two units. Nonetheless, we must ask if a final knowledge product (here I mean one that has answered the driving question but is not “final” in the sense of cognitive representations of changing science ideas) such as the one in the Earth Science 2 unit, is sufficient for evaluating student progress at the end of a unit. Unless a teacher is well-versed in the EIPs as indicators of meaningful science engagement (and also a means to evaluate one aspect of student progression of learning), I would also disagree that knowledge products as processes are useful in the practical sense of student assessment.

Up to this point, I have argued that using scientific modeling as a means for assessment does not serve to indicate meaningful science learning through progressively sophisticated attendance to the epistemic considerations when the materialistic product is emphasized, nor is it a practical form for evaluating student growth when most teachers have limited understandings of how to identify shifts in science metaknowledge. Still, knowledge products such as
diagrammatic models that students have been constructing and revising across an entire unit can offer unique insight into students’ growth in both epistemic thinking and content understanding *from a research perspective*. I do not currently think that most teachers are prepared to successfully, fairly, and time-effectively evaluate meaningfully constructed student knowledge products. The research I shared in this dissertation should ignite a deeper discussion -and future research- as to how to support teachers in this endeavor. At the same time, I also believe that until better scaffolds are erected, teachers will continue to design modeling engagement in their classrooms that likely result in a knowledge product for summative evaluation. My findings can inform decisions in this avenue as well, and I explain further in the next section.

**How can we better support meaningful engagement in “final models”**

Many teachers may be drawn to modeling in the classroom because it seems to inherently contain features salient to evaluation. While scientific modeling is not intended for this purpose, the fact remains that teachers will likely still use them as assessment pieces. As I concluded in this dissertation, approaching scientific modeling as a means to construct a physical product does not support students in meaningful science learning. Based on my findings, I have developed a brief set of guidelines to help teachers focus more on the process of the practice rather than the end product. These guidelines should not replace toolkits already established for supporting teachers in modeling, but rather be used a supplement for approaching knowledge product construction with meaningfulness in mind.
Consider why students are making a knowledge product. Inclusion of scientific practices, specifically modeling, in the classroom is intended for the purpose of knowledge construction (Berland & Reiser, 2009; Jimenez-Aleixandre et al., 2000; Lehrer & Schauble, 2006; Schwarz et al., 2009; Schwarz & White, 2005; Stewart, Cartier, & Passmore, 2005). Using models in other ways does not satisfy the practice call, nor does it appropriately position students as authors of scientific knowledge. Although we argue that attendance to the epistemic considerations should be implicit aspects of practice engagement, teacher framing of audience can better situate learners for meaningful engagement in the practice. As I have explored in this dissertation, prioritizing the goals of the knowledge product as sensemaking or convincing led to more sophisticated use of other epistemic considerations. Conversely, when students believed their goal was mainly to inform an audience, and this goal was bookended by creativity and professionalism in the final product, students failed to construct authentic science knowledge with their models; the models were uni-dimensional representations rather than complex visualizations of scientific thinking. By approaching modeling with complex goals in mind, the data here suggest that learners will be better supported in authentic practice engagement.

Prioritize evidence in the model construction. Another striking trend from my data was that students frequently failed to cite the use of evidence in the construction of their final models when the models were approached as products. To support more meaningful engagement in the modeling practice that prioritizes justification of ideas using evidence, teachers should not only prioritize
justification in the classroom discourse, but also draw out student thinking about justification as they construct the knowledge product. Framing the use of the model as a means to persuade an audience is one such way to leverage justification of ideas (Berland & Hammer, 2012). There are many toolkits available to teachers that support the foregrounding of evidence and reasoning in the classroom (Erduran, Simon, & Osborne, 2004; Simon, Erduran, & Osborne, 2006); for sustained meaningful engagement across an entire unit, what is important in the classroom should also be important to the final model construction.

**Approach models as continuous representations for explaining phenomena.** Drawing upon the “of vs for” framework (Passmore et al., 2014), it is important for teachers to consider more complex epistemic uses of models as cognitive tools for scientific thinking. Models that are approached as creative ways to show a phenomenon, such as with the data I have presented, do not always push learners to unpack the phenomenon in sophisticated ways. Incorporating a list of words from a rubric is not an indication of student growth in understanding, and therefore teachers should be more interested in the students’ use of the model to explain how and why a phenomenon occurs. Creativity rests in the variety of representations students may choose for explaining phenomena; scale, representations of invisible components, and interactions of components all present opportunities for students to develop new ways to make their thinking visible. Treating “final” models not as stopping points that meet standards, but as the most salient iteration of ideas in a sequence of iterations to answer a
question can reframe the task as a practice rather than as a content-driven product.

Parting Words

I began this dissertation by discussing the challenges facing teachers as they engage in authentic science practices with their students, and I now end in much the same way. Science, as discipline and as a way of thinking, is complex and requires ingenuity, collaboration, and continuous construction of knowledge. Students should experience these authentic parts of science in the classroom, but the reality is that teachers are in general vastly unprepared to scaffold these kinds of interactions. My goal in this dissertation was to examine the variety of ways in which one teacher approaches the practice of modeling with her students with the expectation that the findings would inform not only our understanding of construction of meaning around a practice in the classroom, but also contribute to our knowledge of teacher approaches to modeling. Ultimately, the data and analysis I have presented within indicate that meaningful modeling engagement is possible both in the classroom and as a final knowledge product with appropriate supports.

At a larger scale, this research contributes to a theory-based discussion on knowledge product construction, specifically models, and their use as “final-form” products in classroom settings. I expect that this conversation will continue for some time, as there are many practical and theoretical facets to the use of knowledge products in schools, not to mention the variety of parties at play. Students deserve to experience authentic exposure to science; teachers must be
supported in their roles without undue burdens. This research builds upon a solid foundation of understanding the capabilities of students and teachers in practice engagement.

On a more practical level, this research informs practitioner actions. As I discussed in this chapter, using models as assessment pieces elicits rote enactments from students that are not indicative of their understanding of science metaknowledge (or even their content knowledge at times). While I weighed the affordances and limitations of knowledge products as evaluative measures, I refrained from a judgment call in either direction, as a more universal discussion is needed. With that in mind, I provided several considerations for teachers as they think about meaningful ways to incorporate modeling as a practice (and potentially a product) in their classrooms. Again, my research adds to the variety of fruitful ways teachers can support students in authentic science.

To sum, the findings indicate that not only is co-construction of meaningfulness possible in the classroom, it also takes a variety of forms. Furthermore, engagement in modeling as knowledge construction is far more authentic for students than using models as materialistic end products. These findings support the body of knowledge that is meeting the challenge of supporting teachers and students in meaningful science engagement.
Appendix

Table A1

_Coding rubric with examples for the epistemic consideration of Audience. Subcodes for Why and How are listed in from least to most sophisticated ideas within each category._

<table>
<thead>
<tr>
<th>Code</th>
<th>Example of Student Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>No one</td>
<td><em>I don’t know</em></td>
</tr>
<tr>
<td>Not obvious/Haven’t thought</td>
<td><em>I don’t know...another student maybe?</em></td>
</tr>
<tr>
<td>about it before</td>
<td></td>
</tr>
<tr>
<td>Anybody</td>
<td><em>Anyone who wanted to learn about energy could use it.</em></td>
</tr>
<tr>
<td>Self (me)</td>
<td><em>I think it’s mainly for me to understand it.</em></td>
</tr>
<tr>
<td>Teacher</td>
<td><em>Well, I wrote this because my teacher said I needed to put in there.</em></td>
</tr>
<tr>
<td>Less knowledgeable other</td>
<td><em>Probably a 6th grade class could use it to learn.</em></td>
</tr>
<tr>
<td>(younger student)</td>
<td></td>
</tr>
<tr>
<td>Peer (with other ideas)</td>
<td><em>You could use this is there is someone in your class who doesn’t think that that’s how storms work</em></td>
</tr>
<tr>
<td>The class community</td>
<td><em>I would say it was mostly for us to figure out why the population was changing.</em></td>
</tr>
<tr>
<td>Other ideas</td>
<td><em>I made it for anyone coming to science night.</em></td>
</tr>
<tr>
<td>A professor/WSU</td>
<td><em>It is probably for the researchers at Wright State.</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Why</th>
<th></th>
</tr>
</thead>
</table>

258
<table>
<thead>
<tr>
<th>What is the purpose of the model? Why does it matter?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communicating (Demonstrate/Inform)</strong></td>
</tr>
<tr>
<td><strong>Communicating - Emphasizing clarity of the model</strong></td>
</tr>
<tr>
<td><strong>Communicating - Trying to help audience understand a confusing piece</strong></td>
</tr>
<tr>
<td><strong>Sensemaking</strong></td>
</tr>
<tr>
<td><strong>Persuade</strong></td>
</tr>
</tbody>
</table>

**How**

What does the person do with their model with respect to the audience?

- I don’t know
- I don’t know/ I wouldn’t do anything.
- I would just read them my model and then they would believe me.
- I would show this to them and ask them, if this isn’t true, they why can you not see in a really dark basement and maybe then I could turn off all the lights and they would see that you can’t see without a light source.
Table A2

*Coding rubric of epistemic consideration of Justification with student examples. All responses that align with use of justification are coded for both source and nature of justification.*

<table>
<thead>
<tr>
<th>Source</th>
<th>Code</th>
<th>Example of Student Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>(No particular progression)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No evidence</td>
<td>No evidence</td>
<td><em>We didn’t use any evidence</em></td>
</tr>
<tr>
<td>Authoritative source (teacher, Google, book)</td>
<td>Authoritative source</td>
<td><em>My teacher told us...</em></td>
</tr>
<tr>
<td>General everyday experience</td>
<td>General everyday experience</td>
<td><em>Everyone has been in a hot room before</em></td>
</tr>
<tr>
<td>Personal experience</td>
<td>Personal experience</td>
<td><em>One time I went to Old Man’s cave and saw...</em></td>
</tr>
<tr>
<td>Hypothetical data/scenario</td>
<td>Hypothetical data/scenario</td>
<td><em>Imagine if someone turned out all the lights...</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reasoning</th>
<th>Code</th>
<th>Example of Student Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>(No particular progression)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0. No justification</td>
<td>0. No justification</td>
<td><em>We did an experiment with the cups and the water.</em></td>
</tr>
<tr>
<td>1. Identify relevant information</td>
<td>1. Identify relevant information</td>
<td><em>We did an experiment with the cups and the water and we saw that the water level went down.</em></td>
</tr>
<tr>
<td>2. Simple interpretation</td>
<td>2. Simple interpretation</td>
<td><em>We did an experiment with the cups and the water and the water level went down which means the water escaped into the air.</em></td>
</tr>
<tr>
<td>3. Multiple source interpretation; includes triangulation of multiple sources or multiple</td>
<td>3. Multiple source interpretation; includes triangulation of multiple sources or multiple</td>
<td><em>We did an experiment with the cups and the water to see that the water escaped into the air, and we also did another experiment with the smoke and the cardboard boxes to show that the</em></td>
</tr>
</tbody>
</table>
interpretations of various sources | warmer air will rise, so that shows us how clouds form and rise up.

4. Complex interpretations

| 4a. Chaining Claims | We did the experiment with the cups and the water and the water went down, which means the water escaped into the air. We also saw that when we heated up the water, it went into the air faster, which means that the water molecules were moving even faster. |
| 4b. Counterfactual argument/rebuttal | Same as above, provides a rebuttal to why the water couldn’t have had a leak |
Table A3

Coding rubric of the epistemic consideration of nature of account in student interviews.

<table>
<thead>
<tr>
<th>Naming Factor</th>
<th>Code</th>
<th>Example of Student Ideas (using How and why seasons occur)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a. First factor involved in the mechanism</td>
<td>Student names <strong>tilt of the earth</strong> as a major factor behind seasons</td>
<td></td>
</tr>
<tr>
<td>1b. Second factor/noun involved in the mechanism</td>
<td>Student names <strong>sunlight intensity</strong> as a major factor behind seasons</td>
<td></td>
</tr>
<tr>
<td>1c. Other ideas/nouns not necessarily linked to the mechanism</td>
<td>Other factor such as closeness to sun, sun is out longer, closer to the equator, etc.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reasoning</th>
<th>Code</th>
<th>Example of Student Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a. Student reasons/unpacks the involvement of factor 1a</td>
<td>Response refers to a <strong>specific position of the earth related to tilt</strong> (in relation to the sun, in its orbit, etc.)</td>
<td></td>
</tr>
<tr>
<td>2b. Student reasons/unpacks the involvement of factor 2b</td>
<td>Response discusses the <strong>angle/directness of light</strong> coming from the sun as related to intensity</td>
<td></td>
</tr>
<tr>
<td>2c. Student reasons/unpacks the involvement of factor 2c</td>
<td>Specific verb for how/why [1c factor] is responsible for difference in seasons</td>
<td></td>
</tr>
</tbody>
</table>
Table A4

**Coding rubric for cognitive agency in providing the mechanistic account of a phenomenon during classroom discourse.**

<table>
<thead>
<tr>
<th>Classroom Discourse Mechanism</th>
<th>Code</th>
<th>Discourse Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRE (Initiate, Respond, Evaluate). Teacher walks students through a basic mechanism via low-level recall</td>
<td>Edith: Teeth just breaks down the food while the saliva… Mrs. L: Breaks it down how? Edith: Like, you’re grinding it. Mrs. L: Good, and what kind of changes do you make to your food? Edith: Um, it’s making it smaller and smaller in appearance. Mrs. L: Is it still the same substance? Edith: Yeah. Mrs. L: So it’s a… Edith: Um, physical? Mrs. L: Right. It’s a physical change.</td>
<td></td>
</tr>
<tr>
<td>Teacher does work - Teacher explains mechanism behind a phenomenon with little to no cognitive input from students</td>
<td>Mrs. L: Saliva, okay. So it chemically breaks down your food into substances. You start digesting your food the moment you stick it in your mouth. Your saliva breaks down your starches. Doesn't break down fats, doesn't break down proteins. Pay attention to the way the food is in your mouth when you eat today. With a ham sandwich, pay attention to the difference in texture between your bread and the ham and cheese. Breaks down starches into sugars…</td>
<td></td>
</tr>
<tr>
<td>Students do work - Students explain the mechanism behind a phenomenon with minimal input from teacher</td>
<td>Sam: How the light intensity…um, how- it technically…how the light intensity causes different temperatures on the earth. Mrs. L: Okay, so differences in light intensity okay. So now we need to know why is the light intensity different. Pandora: Because of the lines of longitude -no, latitude. The lines of latitude absorbs light.</td>
<td></td>
</tr>
</tbody>
</table>
### Table A5

*Emergent codes in classroom discourse regarding agentive sensemaking and examples.*

<table>
<thead>
<tr>
<th>Sensemaking</th>
<th>(Who is doing the cognitive work of making connections among data?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>Discourse Examples</td>
</tr>
</tbody>
</table>
| Teacher-led | Mrs. L: Where does chemical digestion happen in your mouth? How does that happen?  
  Cal: Um, in your saliva?  
  Mrs. L: In your saliva and if it's chemical digestion, what's that implying?  
  Cal: That you're breaking it apart.  
  Mrs. L: Right. Through what process?  
  Cal: Uh...  
  Mrs. L: *Okay, let me try to help you. It says, "Mechanical digestion physically breaks down your food." Physical change. Still a cracker, just a different shape, right?* |
| Student-led | Freya: I was gonna say like when we did the board experiment with the graph paper. When we had it-when we had it-when we had the board pointing straight up and we had the flashlight-  
  Mrs. L: When we had the light perpendicular to the surface of the core-  
  Freya: It had a small focused beam of light, which would kind of be like how the sun shines on the equator. And then when we tilted the board back, the light intensity become more spread out. So there would be like, a less focused point of light there. |

### Framing

(Who decides or directs the purpose of the activity?)

| Code | Discourse Examples |
| Teacher-led | Mrs. L: We need to think about who is the model for.  
  That sounds like something we need to talk about. Who is the model for? We call that the audience. *Aren't we* |
making our model of metabolism for our families...to explain what happens in your body with the food that you eat and how exercise relates to that?

Bob: Shouldn’t we be making this more geared toward other eighth graders?
Max: Oh, yeah. So let’s get rid of the mouth since we already know that.

<table>
<thead>
<tr>
<th>Code</th>
<th>Discourse Examples</th>
</tr>
</thead>
</table>
| Student adds a new idea or asks a question that implies higher-level thinking | Alfred: I’m not sure if this is related, but why can’t you digest corn?  
Mrs. L: Why can’t you do-do you mean the outside of the corn? The inside part of the corn you can, the outside, you don’t. It’s largely cellulose, so it’s more like a fiber, yeah. You don’t... you know what he’s talking about?  
Violet: Yeah  
Mrs. L: Okay.  
Kyle: Why can’t you digest fiber? |
| Student responds or adds to another student’s new idea or question              | Alfred: I’m not sure if this is related, but why can’t you digest corn?  
Mrs. L: Why can’t you do-do you mean the outside of the corn? The inside part of the corn you can, the outside, you don’t. It’s largely cellulose, so it’s more like a fiber, yeah. You don’t... you know what he’s talking about?  
Violet: Yeah  
Mrs. L: Okay.  
Student: Why can’t you digest fiber? |
| Teacher solicits ideas from students                                             | Mrs. L: Okay, so you have water vapor and you have dew but you don’t know how-how they’re linked to each other?  
Scott: Yeah, it doesn’t make sense. |
Mrs. L: *What do you think, Red? Does this show you how dew forms?*

Jean-Luc: Why does gum, like, some gum makes you have a lot of saliva?
Mrs. L: *Why does it make you have a lot of saliva? I don't know. Would you like to write that down?*

Gary: What would happen if, like, since there’s so many like, unnecessary stuff, what if you took away all of the unnecessary organs?
Mrs. L: *If they’re unnecessary, your body would start functioning well.*
Table A6

**Emergent codes in student interviews and examples of those codes.**

<table>
<thead>
<tr>
<th>Code</th>
<th>Examples of Student Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of Evidence - salient sources of evidence</td>
<td></td>
</tr>
<tr>
<td>Empirical Data</td>
<td><em>Maybe something that was tested multiple times and then concluded.</em></td>
</tr>
<tr>
<td>Experiences</td>
<td><em>But good evidence, I think comes from you experiencing it for yourself and you trying to do it by yourself.... And then um, and you know I know we have seasons, because the weather changes and that sort of thing. We have winter and summer and fall and spring.</em></td>
</tr>
<tr>
<td>Facts (authoritative)</td>
<td><em>So like, good evidence would be factual....So it would be like you have teeth. But...so. And then you use those teeth to break down your food.</em></td>
</tr>
<tr>
<td>Models</td>
<td><em>I think it would be a model with a short explanation of it because models are really easy to interpret.</em></td>
</tr>
<tr>
<td>When do we use evidence</td>
<td></td>
</tr>
<tr>
<td>To convince</td>
<td><em>A lot of times when I'm trying to prove something to somebody else, I talk about like an experiment that we did in class, or logic.</em></td>
</tr>
<tr>
<td></td>
<td><em>Because like- because I didn't know like before- like when we started this a little bit, I didn't know why it uplifted very much. So like then I started to understand like the continental crust was like less density so it was like almost like on top of the mantel so it could only go up</em></td>
</tr>
<tr>
<td>To learn (personal)</td>
<td><em>Like, if you were teaching the body, you can't like-you can't really prove to someone that there's -well.</em></td>
</tr>
</tbody>
</table>
You could prove to someone that there's food in your blood and stuff because you can test the plasma and like, so... I guess you can use evidence for that stuff.

Usually if someone says something and another person says, no, that's wrong, or I don't agree with that, then Ms. L will have us like, ok, back that up with evidence. So each side will find evidence in their book and be like, see now this is what proves that. Or other models.

We didn't really use a lot because we felt that it wouldn't - because, I mean, it's all things that you kind of know happen. Like you know that you breathe in, you know that you eat food, and like you know that a lot of the stuff happens, but we could have used a little bit more evidence, although we didn't use that much.

<table>
<thead>
<tr>
<th>Code</th>
<th>Examples of Student Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Why we make models</td>
<td></td>
</tr>
<tr>
<td>For our learning</td>
<td>You can learn some things from reading, but I - I think you understand it - or you get it a lot more if it's coming from your head.</td>
</tr>
<tr>
<td>To show/demonstrate</td>
<td>I think, I think that'd be okay [if a model was accurate, but not neat], but I also think that, when you have your model, it’s good to present it in a professional way, and having stuff being messy isn’t really professional, so.</td>
</tr>
<tr>
<td>emphasis is on passive</td>
<td></td>
</tr>
<tr>
<td>knowledge</td>
<td></td>
</tr>
<tr>
<td>To teach/explain</td>
<td>We use them to explain our knowledge so we can explain -so we can show and explain to other people.</td>
</tr>
<tr>
<td>emphasis on interaction</td>
<td></td>
</tr>
<tr>
<td>with reader</td>
<td></td>
</tr>
<tr>
<td>Why we use models</td>
<td></td>
</tr>
</tbody>
</table>

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To understand something difficult or look at it in a new way

Like, I know in our class, one of the things that we were struggling to write down and put into words was the why of certain things. And I think that reading other people’s explanations and looking at the models and stuff - it helped us to see the people who did put down why and to be able to fit that into our models better.

<table>
<thead>
<tr>
<th>Code</th>
<th>Why we critique models</th>
</tr>
</thead>
<tbody>
<tr>
<td>To get the right answer</td>
<td>Because if you were to study on it for a test, you'd be studying all the wrong stuff. And if you were going to show it to other students, then they would get the wrong idea.</td>
</tr>
<tr>
<td>To get a better product</td>
<td>You might make a model and think it's the best thing ever, but if you're making a model for someone else, then you have to make sure that the someone else you're showing it to understands it. So it really helps to have another opinion.</td>
</tr>
</tbody>
</table>
References


Lederman, N. G. (1999). Teachers’ understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of research in science teaching, 36*(8), 916-929.


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