Teaching Science as Epistemic Practice:
Examining Teachers’ Conceptions and Instruction in Middle School Science Classrooms

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To my mother and father -

The ones who taught me to find my passion and shoot for the stars.
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Introduction

Preparing students to be scientifically literate and equipped to solve complex problems in today’s society requires students to understand the work of scientists and how the scientific community constructs knowledge. To this effort, recent science education reform has emphasized a focus on teaching science as practice, rather than as a prescribed method of experimentation or a defined body of existing knowledge. This focus on practice strives to engage students in the authentic work of scientists so they gain deeper understanding of scientific knowledge and how that knowledge is established. A key goal of framing science as practice in classrooms is to emphasize participation in the disciplinary activities of science and the epistemic nature of these activities. In order to make this vision of science education a reality in classrooms, teachers must be well prepared to teach science in this way. Previous research has largely investigated supporting epistemic practices via instructional materials, but these materials must be complemented by effective support from teachers. Teachers play a crucial, active role in how and what is taught in classrooms (Remillard, 2005), so ensuring that teachers are prepared to teach science as epistemic practice is essential. While changes spurred by new educational standards (namely the Next Generation Science Standards [NGSS] in the United States; NGSS Lead States, 2013) are underway, teachers need guidance to better understand and implement a focus on practice in their science classrooms (Reiser, 2013; Sandoval, Kawasaki, Cournoyer, & Rodriguez, 2016).

Helping students understand and successfully participate in the epistemic practice of science requires significant changes from traditional science education, which often teaches science through proceduralized, unrelated activities (Windschitl, Thompson & Braaten, 2008). While researchers have theorized about the epistemic nature of science, the connections between
activities that are rooted in this epistemology are often absent in classrooms. Teaching science as epistemic practice requires more than simply using the term “practice” in educational standards, objectives, and curricula; it necessitates a fundamental reframing of science education to align with the epistemic pursuits of the scientific community to develop explanations about phenomena in our world. Conceptualizing the authentic work of scientists as practice encompasses the shared goals, norms, resources, and ways of constructing knowledge in the scientific community (Wenger, 1998). This perspective highlights science as a way of understanding, evaluating, and representing the world (Lehrer & Schauble, 2015). More specifically, the epistemic practice of science is an effort to explain natural phenomena through processes of generating questions, conducting investigations, analyzing and interpreting data, and constructing evidence-based arguments. While these processes are traditionally taught as isolated, sequential skills (Windschitl et al., 2008), they are interdependent and all contribute to the goal of constructing scientific knowledge (Lehrer & Schauble, 2015; Reiser, 2013). In order for students to successfully and knowledgably participate in science as epistemic practice, students need to understand why and how certain processes are used in pursuit of this goal in science and the criteria for successful participation in science (Barzilai & Chinn, 2018).

Helping students develop this understanding of science means that teachers must first understand and know how to teach science in this way. Viewing science as practice is a new perspective for many current teachers (Osborne, 2014; Reiser, 2013; Sandoval et al., 2016). Developing new curricula and educational standards focused on epistemic practice is important, but how these efforts are actually implemented in classrooms depends heavily on the teacher (Remillard, 2005). A teacher’s knowledge, as well as other contextual factors, influences how a particular curriculum is enacted (Remillard, 2005). Importantly, there is increasing evidence that
teachers’ epistemic cognition plays a role in how they approach teaching and in the learning
goals they set for their students (Bråten, Muis, & Reznitskaya, 2017; Buehl & Fives, 2016; Kang,
2008; Lunn Brownlee, Ferguson, & Ryan, 2017; Yadav, Herron, & Samarapungavan, 2011). As
Buehl and Fives (2016) argue, “the need for teachers to engage in epistemic cognition is
exponentially higher than it is for students as teachers both learn and design contexts for the
learning of others” (p. 248). Thus, it is crucial that teachers understand science as epistemic
practice aimed at developing knowledge and explanations about the world, so that they can
frame science in this way for their students.

Prior work, however, suggests that teachers need more support and preparation to create
environments within their classrooms that reflect and help students learn to participate in the
practice of the scientific community. For example, Sampson and Blanchard (2012) have found
that teachers struggle to engage students in scientific argumentation, an important process for
building knowledge and understanding in the scientific community. They suggest that these
challenges may be due to teachers’ limited pedagogical knowledge, understanding of how to
participate in argumentation, or understanding of the purpose of argumentation in science
(Sampson & Blanchard, 2012). Other scholars have found that teachers may struggle to know
how to teach student about the role of evidence to support claims (McNeill & Knight, 2013),
another central feature of scientific practice. More recently, Sandoval, Kawasaki, Cournoyer, and
Rodriguez (2016) found that science teachers trying to implement a new focus on practice often
did not actually frame science in their classrooms as an epistemic practice of developing
understanding and truly engage students in the practice of science. Instead, teachers more often
engaged students in activities to reinforce already learned concepts, learn a particular method, or
assess science knowledge (Sandoval et al., 2016). These types of practice-related activities do
not embody the vision to foster scientific communities within classrooms. Sandoval and his colleagues (2016) suggest that the current prevalence of such activities is not surprising given that teachers have, for the most part, not been prepared to teach science as a epistemic practice. An important reason that teacher education programs have struggled to prepare teachers for science focused on practice is because “teaching to support these valued goals remains underdefined and undertheorized” (Windschitl, Thompson, Braaten, & Stroupe, 2012, p. 884).

To address this issue and prepare teachers to successfully teach students how to participate in the epistemic practice of science, we need to (a) better understand and define effective instruction that aligns with the epistemic practice of science and helps build scientific communities in classrooms. There are minimal practical guidelines for teaching science as practice that are strongly and clearly aligned with the epistemological foundations of science. We currently know little about how teachers can effectively build scientific communities within their classrooms through instruction that is aligned with the epistemic practice of science. Being able to identify instruction that aligns with this perspective will be instrumental for establishing and recommending effective instructional practices teachers can use to support their students’ participation in science. To help teachers enact effective instruction in their classrooms, we also need to (b) better understand how teachers understand and reflect on their own teaching as supporting participation in the epistemic practice of science. Reflection has been shown to be powerful way to assess and improve epistemic cognition and to promote change in teachers’ practice (Bråten et al., 2017; Lunn Brownlee et al, 2017). Asking teachers to reflect on their own instructional practices will help us elicit and dig deeper into teachers’ conceptions of their own practice and their conceptions of the epistemic nature of science. Such reflection may also offer insights into how educational researchers and teacher educators can effectively support teachers
to improve their instruction about science as epistemic practice. We know little about how teachers think about the epistemic goals of science or how they view the activities their students participate in as all contributing to constructing knowledge as scientific community. Eliciting teachers’ knowledge about these ideas through reflection on their own teaching will be useful for better understanding the instruction that occurs in their classrooms and how to support teachers’ learning in the future. Furthering our understanding of these two issues – (a) effective instruction that aligns with the epistemic practice of science and (b) how teachers understand and reflect on their own instruction for science as epistemic practice – is a crucial step towards making recommendations about how teachers can support their students understanding and helping teachers enact such instruction in their classrooms.

This dissertation addresses the issues stated above. In Chapter 2, we present the theoretical basis and implications for framing science as epistemic practice in education. We describe how a theoretical framework of epistemic practices proposed by Barzilai and Chinn (2018), the Apt-AIR framework, aligns with these implications of teaching practice and apply this framework to conceptualize a vision for teaching science as epistemic practice. In Chapter 3, we investigate how teachers provided instruction in their classrooms for understanding science as epistemic practice, as conceptualized in Chapter 2, and how this instruction related to students’ understanding of and participation in science as epistemic practice. In Chapter 4, we look more closely at several of the teachers from Chapter 3 through in-depth interviews to better understand how teachers conceptualized the epistemic nature of scientific practice and understood their own instruction for science as epistemic practice. Finally, we present final conclusions and implications of this body of work in Chapter 5.
Teaching Science as Epistemic Practice

Teaching science as a practice of developing understanding and explanations about the natural world has become a prominent goal in science education. Helping students learn to participate in the work of the scientific community and understand the epistemic nature of this work calls for substantial changes to current instructional approaches, which often present science as a set of particular procedures or body of facts students should learn. Teaching science as epistemic practice requires a fundamental reframing of the activities students engage in and the ways in which teachers support students. In order to make this vision of science education a reality in classrooms, teachers must be well prepared and understand how to teach science in this way. An important first step in this preparation is characterizing teachers’ instruction to help students understand and participate in science as epistemic practice.

Conceptualizing the authentic work of scientists as practice encompasses the shared goals, norms, resources, and ways of constructing knowledge in the scientific community (Wenger, 1991). This perspective highlights science as a way of understanding, evaluating, and representing the world (Lehrer & Schauble, 2015). More specifically, the epistemic practice of science is an effort to explain natural phenomena through processes of generating questions, conducting investigations, analyzing and interpreting data, and constructing evidence-based arguments. As will be further explained later, we describe these as epistemic processes (Barzilai & Chinn, 2018; Chinn, Rinehart, & Buckland, 2014) rather than “science practices” to emphasize their role in the larger epistemic practice of science. While these processes are frequently taught as isolated, sequential skills (Windschitl, Thompson & Braaten, 2008), they are interdependent and all contribute to the goal of constructing scientific knowledge (Reiser, 2013;
Lehrer & Schauble, 2015). In order for students to successfully and knowledgably participate in science as epistemic practice, students need to understand the overarching goals or pursuits of science, the purposes for the particular processes used in science, and the criteria for successful participation in science (Barzilai & Chinn, 2018).

While researchers have theorized about the epistemic nature of science, the connections between activities that are rooted in this epistemology are often absent in classrooms. Prior work suggests that teachers need guidance to better understand and implement a focus on science as epistemic practice in their classrooms (Reiser, 2013; Sandoval, Kawasaki, Cournoyer, & Rodriguez, 2016). In order to prepare teachers to help their students participate in the epistemic practice of science, we must first better understand what teaching for such participation looks like in classrooms. There are theories about the epistemic nature of scientific practice, but little work has investigated how teachers provide instruction to help students understand and participate in science as epistemic practice, and practical guidelines for instructional practices that support this learning are not well defined. Currently, there are minimal guidelines for teaching science as practice that strongly align with the epistemological foundations of science. Better conceptualizing instruction about science as epistemic practice is instrumental for establishing and recommending effective instructional practices teachers can use to support their students’ participation in science.

In this chapter, we aim to address this issue by discussing what a vision for teaching science as epistemic practice really means for education and proposing instruction to support students’ understanding of science as epistemic practice. To do this, we use a theoretical framework of epistemic practice, the Apt-AIR framework (Barzilai & Chinn, 2018), that specifies the aspects of an epistemic practice students would need to understand in order to
successful participation. We connect literature on the theoretical conceptions of epistemic practice and the more applied discussions from science education literature about teaching “science practices” in an effort to better characterize instruction that aligns with the epistemic practice of science to help create communities of scientific practice in the classroom. This work is needed to specify instruction that is both rooted in the epistemology of the practice of science and contextualized for implementation in science classrooms, so that teachers may successfully bring a focus on epistemic practice into their classrooms.

This chapter is organized as follows. First, we discuss what it means to consider science as epistemic practice from a theoretical perspective and the implications this has on framing science as practice in education. Second, we describe how a theoretical framework of epistemic practice proposed by Barzilai and Chinn (2018), the Apt-AIR framework, aligns with these implications of teaching practice and explain our rationale for using this framework. Finally, we apply this framework by synthesizing prior research in science education to conceptualize a vision for teaching science as epistemic practice and propose guidelines for instruction.

**Theoretical Implications of Practice for Science Education**

Teaching students how to participate in the practice of science has become a central goal of science education. Science education has previously emphasized notions such as “the scientific method,” “inquiry,” and “hands-on” experimentation, but focusing on “practice” has important epistemic connotations and proposes a different perspective to how and what students should learn in science. The theoretical conceptualizations of practice have critical implications for framing science as practice in the classroom. In this section, we discuss theoretical features of practice based on a sociocultural and situated perspective of learning, specifically the importance of (a) authentic participation and (b) conveying the epistemology of science.
The theoretical notion of practice is rooted in the sociocultural perspective of learning and, more specifically, the situated nature of learning. Practice is the social way that people negotiate meaning and construct knowledge (Wenger, 1998). As Wenger described, “The concept of practice connotes doing, but not just doing in and of itself. It is doing in a historical and social context that gives structure and meaning to what we do” (Wenger, 1998, p. 47). A central theoretical feature of practice is participation and engagement in activity.

Participating in practice is often associated with the formation of communities. While not all communities are defined by practices, and not all practices have clearly identifiable communities, the association of practice and community defines a community of practice (Wenger, 1998). A community of practice coheres through mutual engagement in the practice, common goals, and a shared set of social norms, language, and behavior that are special to that community (Wenger, 1998). For science, the scientific community is defined by their mutual engagement in the practice of science, their common goals of developing increasingly better explanations of phenomena, and their shared criteria and processes for constructing knowledge and understanding to explain the natural world.

In a community of practice, learning is a process by which people become members of the established community (Lave, 1991; Wenger, 1998). Lave (1991) discusses situated social practice as a view of learning that emphasizes how meaning and activity are socially negotiated and focuses on people being engage in activity. From this perspective, learning is engagement and participation in authentic practice:

Learning is not reified as an extraneous goal or as a special category of activity or membership. Their practice is not merely a context for learning something else.

Engagement in practice – in its unfolding, multidimensional complexity – is both the
stage and the object, the road and the destination. What they learn is not a static subject matter but the very process of being engaged in, and participating in developing, an ongoing practice (Wenger, 1998, p.95).

Framing learning science as participating in practice changes the focus of science education from learning a body of scientific information or how to perform a set of scientific skills. Rather, this perspective implies on focus on learning how to engage in the ongoing knowledge building processes of the scientific community. Learning science content and skills come with successfully participating in the epistemic practice of science, but the prioritized end-goal is that students understand what it means to participate in the scientific community and not that they remember specific content or procedures.

A second important theoretical feature of practice is that participating in the practice of a community reflects a particular epistemology or way of building knowledge in that community. From a situated learning perspective, knowledge is contextualized within disciplinary activities, and people participate in social practices to solve epistemic problems within their community (Sandoval, Greene, & Bråten, 2016). Authentic disciplinary practices that aim to build knowledge and solve new problems can be described as epistemic practices (e.g., Sandoval, Greene et al., 2016). Scientists, for example, engage in evidence-based scientific argumentation to refine ideas and to construct explanations about natural phenomena. Framing science as a practice aims to reflect the epistemology of science, or the valued ways that scientific knowledge is constructed and accepted in the community. Learning science as a set of rules or steps (i.e. the scientific method) is not sufficient for learning how to actually participate in the scientific community, nor for describing the epistemic value of scientific knowledge (Ford, 2015). Scientists’ efforts to solve problems and explain phenomena cannot be simplified to a pre-
determined list of rules for students to follow, because any such list would dilute the epistemic, explanation-seeking nature of science.

Framing science as practice, instead, conveys a crucial epistemic idea that science is a connected cycle of processes by which scientists strive to construct and improve explanations. The epistemic practice of science is not a linear, ordered set of steps or skills to be followed to reach a conclusion. Rather, the practice of science is composed of various processes by which the scientific community develops explanations and uses data to defend arguments for their explanations (Lehrer & Schauble, 2015). A variety of processes might be used iteratively in different situations, and the end result is rarely a final, confirmed answer to a question. This perspective provides a more authentic view of science than traditional educational perspectives, such as the scientific method. Critics of the scientific method often argue that the depiction of a universal, linear scientific method misrepresents science (Ford, 2015, Rudolph, 2005; Stroupe, 2015; Windschitl et al., 2008). Notably, science education that is based on the scientific method is often comprised of procedural and disconnected tasks that are inconsistent with the knowledge building efforts of scientists (Duschl, 2008; Windschitl et al, 2008). While the steps and procedures illustrated in this traditional method play a role in science, they do not encompass an important epistemic aim of science to better explain phenomena, which is rooted in continual critique and evaluation to build knowledge (Ford, 2015). The emphasis on processes of constructing, critiquing, and refining explanations is an important epistemic aspect of science that can be reflected by a practice perspective, but is not represented in the scientific method. While methods or skills are structured and pre-defined, practices convey a sense of on-going progress and a constant goal towards improvement (Ford, 2015; Lehrer & Schauble, 2015).
Additionally, education based on students’ participating in practice is “epistemologically correct” because there is a strong connection between what is learned and how it is learned (Wenger, 1998, p. 101). Meaningful participation in science does not solely focus on knowing content or knowing decontextualized skills. From the perspective that learning occurs through participation and knowledge is reflected in practice (Lave, 1991; Sandoval, Greene et al., 2016; Wenger, 1998), practice and content should be learned simultaneously, as neither can be sufficiently understood alone. Rather than learning science concepts from a textbook or lecture, learning science concepts through participating in the practice of science more closely reflects how scientists learn and discover new concepts. The focus on practice promotes engaging in epistemic practice as the process through which students learn science content: knowledge and understanding of science concepts are learned through engaging with the epistemic practice of science, and the epistemic practice of science is learned in the context of meaningful science concepts (NGSS Lead States, 2013; Sandoval, Kawasaki et al., 2016). Thus, framing science as practice proposes teaching the epistemological commitments of science by integrating the conceptual and epistemic aspects of science in the classroom (Duschl, 2008).

The key features of practice discussed here—promoting authentic participation and reflecting the valued epistemology of a community—suggest that practice entails participating in the epistemic efforts of a community. Teaching science as a practice can, therefore, be viewed as teaching students to participate in the epistemic practice of science. Science education reform and research on teaching students “science practices” (e.g., NGSS) does not always discuss this perspective as a focus on epistemic practice. This is problematic for translating what makes a practice-focused perspective of science education different from previous approaches. The theoretical implications of practice highlight the importance of teaching science in a way that
conveys the epistemic pursuit of building scientific knowledge and helps students learn how to participate in this effort. From this perspective, it is important to understand how teachers’ instruction is aligned with the epistemic practice of science and how teachers can build scientific communities within their classrooms.

**A Framework for Describing and Teaching Epistemic Practice**

Building on the theoretical notion of practice, a useful approach to teaching the epistemic practice of a community, like science, would incorporate the key aspects of practice described above and reflect the contextualized nature of epistemic practice within a domain. Epistemic practices are defined as the disciplinary practices of a community that aim to build and disseminate knowledge (Sandoval, Kawasaki et al., 2016). The valued epistemic goals and ways of achieving those goals are defined by and situated within the particular community. Further, understanding and learning about the epistemic goals and knowledge building processes of a community is situated in activity, or participation in the epistemic efforts of the community (Sandoval, 2015; Sandoval, Green et al., 2016). From this perspective, to successfully teach science as epistemic practice, it would be beneficial for teachers’ instruction to align with the epistemic practice of science and foster a scientific community in the classroom. A crucial step in supporting teachers to teach science in this way is conceptualizing science and teachers’ instruction from a situated, communities of practice focused lens that captures both the authentic participation in and epistemology of science.

Many approaches to teaching the practice of science that focus on engaging students in scientific inquiry and activities in the classroom are heavily task based (Windschitl et al., 2008). Such approaches are often rooted in “the scientific method” and portray science investigations as linear, defined steps that can be completed in a class period (Windschitl et al., 2008). School
science that is traditionally based on this perspective is often comprised of procedural, disconnected, and unrelated tasks that are inconsistent with the authentic work of scientists (Duschl, 2008; Windschitl et al, 2008). These tasks fail to capture the reasoning and the process of constructing knowledge to explain natural phenomena that “are underpinnings of science’s epistemic privilege” and value (Ford, 2015, p. 1041). The epistemic nature of the practice often can be overshadowed by “doing” science, loosing the larger picture of why students are participating in particular activities and why adhering to particular criteria is important for successful participation.

At the same time, approaches that focus on the epistemology of science and ways that professional scientists build knowledge are often decontextualized or abstract and can leave students with little understanding of how the activities they do in their science classroom constitute participation in science (Sandoval, 2005). For instance, much of the research on helping students learn about the epistemology of science from the nature of science perspective is domain-general and often taught before or separately from science content (Carey & Smith, 1993; Lederman 1992). Learning about the epistemology of science and what “scientists do” in this decontextualized way may not help students understand the epistemic nature of their own work in a science classroom (Sandoval, 2005). Instead, a balanced approach is needed – one that truly supports students’ participation in relevant and valued epistemic activities and helps them understand why these aspects of practice are important in science.

We believe that the Apt-AIR framework (Barzilai & Chinn, 2018), developed from the work of Chinn and colleagues (Chinn & Rinehart, 2016; Chinn, Rinehart, & Buckland, 2014), is well suited to describe science as epistemic practice, to establish what participation in this practice looks like in classrooms and what students learn about the epistemology of science, and
to analyze teachers’ instruction for science as epistemic practice. The Apt-AIR framework frames epistemic practice in terms of a community’s goals of constructing knowledge and how that community strives to achieve those goals. Specifically, this framework describes an epistemic practice in terms of a community’s epistemic aims to construct epistemic products (e.g., knowledge, understanding, explanations), epistemic ideals or criteria by which they create and evaluate those epistemic products, and the reliable epistemic processes that they use to develop knowledge and beliefs (Chinn & Rinehart, 2016; Chinn et al., 2014). Using this lens, we can describe science as an epistemic practice by which the scientific community develops understanding and explanations about natural phenomena by specifying: the scientific community’s goals for building explanations and understanding, the valued criteria or standards held for developing explanations, and the procedures the scientific community uses to develop explanations. Describing science in this way highlights both what someone does to participate in science and the epistemology of science.

In terms of providing guidance for how to teach epistemic practice, describing a practice in terms of epistemic aims, ideals, and reliable processes helps to specify components of epistemic practice that students might need to understand in order to successfully participate and goals for students’ learning with respect to epistemic cognition. The Apt-AIR framework proposes teaching epistemic practice with the goal of apt epistemic performance whereby students successfully participate in epistemic activities, rather than replicate expert practice (Barzilai & Chinn, 2018). From this perspective, the goal of science education is to help students participate in and understand the epistemic activities of science. This goal clearly aligns with the theoretical implications of practice discussed previously, and it situates learning the epistemology of science within participating in the valued activities of the scientific community.
In the remainder of this section, we further explain the Apt-AIR framework with respect to describing epistemic practice and establishing actionable goals for teaching epistemic practice in classrooms. First, we describe what epistemic aims, epistemic ideals, and reliable epistemic processes are and broadly discuss these components in the context of science. Then, we explain the notion of apt epistemic performance and how it addresses authentic participation and understanding the epistemology of a community in the context of science education. We will go into more depth to apply these ideas for use in science education later in this chapter. For now, this section provides an overview of the theoretical framework and our rationale for analyzing the epistemic practice of science from this perspective.

**Describing Epistemic Practice: Epistemic Aims, Ideals, and Reliable Processes**

An epistemic practice can be described as a combination of an epistemic aim, with appropriate ideals, and using needed processes to achieve the aim (personal communication with Chinn, October 6, 2017). *Epistemic aims* are the valued goals that a community has for developing epistemic products, such as knowledge, understanding, explanations, arguments, and useful scientific models (Chinn & Rinehart, 2016; see Chinn, Buckland, & Samarapungavan, 2011 for more discussion on the scope of epistemic cognition). Epistemic aims (e.g., deeply understanding a particular concept or developing an explanation) can be contrasted with non-epistemic aims that are not directed at developing epistemic products (e.g., getting good grades or completing a task). A key epistemic aim of science is constructing scientific knowledge and understanding to explain the natural world (Sandoval, 2015). Scientific explanations (e.g., Berland & Reiser, 2009; McNeill, Lizotte, Krajcik, & Marx, 2006; Sandoval & Reiser, 2004) and scientific models (e.g., Nercessian, 2008; Osborne, 2014; Schwarz et al., 2009; Windschitl et al.,
2008) are central epistemic products that the scientific community strives to create in order to move the field’s understanding about natural phenomena forward.

*Epistemic ideals* are the criteria that a community uses to create and evaluate epistemic products or to evaluate the processes by which epistemic products are created (Chinn & Rinehart, 2016). They are the standards held for what constitutes a good epistemic product and how that epistemic product was generated. Epistemic ideals in science include the criteria that the scientific community holds for creating and evaluating scientific explanations, useful models, or believable knowledge claims. For example, creating scientific explanations and models involves meeting standards for conducting the investigations that produce those products (including experiments, second hand research, or historical science investigations of past events). For experiments, such standards include setting up investigations to purposefully test a hypothesis or prediction and to isolate or manipulate only one variable (Kanari & Millar, 2004; Lehrer & Schauble, 2015; National Research Council, 2012). To create and evaluate scientific explanations and models, there are also standards for analyzing data by identifying variables of interest and looking for relevant patterns or relationships between them (Kuhn, Iordanou, Pease, & Wirkala, 2008; Hug & McNeill, 2008; Lehrer & Schauble, 2015; Sandoval & Reiser, 2004); justifying claims with appropriate data or evidence and providing reasoning for how evidence supports a claim (McNeill et al., 2006; Toulmin, 1958); and persuading others about an explanation or model (Berland & Reiser, 2009; McNeill et al., 2006; Osborne, 2010; Sandoval & Reiser, 2004, Toulmin, 1958).

Finally, *reliable epistemic processes* are the ways or procedures by which a community develops knowledge and beliefs. These are causal processes used to guide the development of epistemic products, and they can range in scale from individual processes like observation and
evaluating the credibility of sources to group processes like argumentation and peer review (Chinn & Rinehart, 2016). Given this varying scale, there seems to be overlap in the literature on what might be considered an epistemic practice and a reliable epistemic process. While some epistemic practices could be thought of as reliable epistemic processes (such as argumentation), it may be that some processes (such as observation) are better conceptualized as contributing to larger practices. One might describe argumentation as a macro process and observation as a micro process. In this paper, we use the terms **reliable epistemic processes** and **epistemic processes** to describe what are often discussed as “science practices” in science education literature and standards, such as the NGSS (NGSS Lead States, 2013)—including generating questions, conducting investigations, analyzing and interpreting data, constructing explanations, and engaging in argument from evidence. These are the valued ways in which the scientific community reliably develops knowledge and explanations about the world (successfully develops epistemic products), and thus, are the reliable epistemic processes that make up the overarching practice of science. Using the lens of the Apt-AIR model, we see “science practices” as a set of epistemic processes that make up the overarching practice of the scientific community. So, rather than each “science practice” having particular aims and ideals, we think about these as the reliable epistemic processes of science to emphasize that they all contribute to the larger epistemic aim of the practice of science: to develop explanations and understanding about natural phenomena and how the world works.

In sum, viewing epistemic practice from this perspective highlights the importance of not only understanding the procedures or processes involved in a practice, but also the role of the processes in the overarching goals of developing epistemic products (e.g., knowledge or explanations) and the criteria that specify successful participation and achievement of the goal.
Conceptualizing the practice of science from this perspective specifies science as a combination of epistemic aims to develop scientific explanations and models of phenomena, standards for justifying claims (explanations or models) with evidence from investigations, and processes that the community agrees on for reliably producing scientific explanations and models. We see the Apt-AIR framework as especially informative for specifying the aspects of epistemic practice one needs to understand in order to successfully participate. We turn next to how the Apt-AIR framework helps to establish educational goals for students to understand these aspects of epistemic practice and knowledgably participate in the practice in classrooms.

**Teaching Epistemic Practices: Focus on Apt Epistemic Performance**

The Apt-AIR framework outlines educational goals for teaching epistemic practice in terms of authentic participation and understanding the epistemology of a community through the notion of apt epistemic performance (Barzilai & Chinn, 2018). Apt epistemic performance occurs when students successfully participate in valued epistemic activities because they understand what they are doing and why the things they are doing are important for successful participation. Barzilai and Chinn (2018) describe this performance as when one “achieves valuable epistemic aims through the agents’ competence” (p. 5), meaning that achieving an epistemic aim can be attributed to a person’s ability and understanding of the epistemic ideals and reliable processes related to what they are doing, rather than luck. The notion of apt epistemic performance offers direction for both what authentic participation in practice can look like in a classroom and what students should understand about the epistemic practice of a particular community.

Translating the idea of authentic participation into a classroom raises questions about what constitutes authenticity in this setting (Barzilai & Chinn, 2018; Russ, 2014). Some
proponents of teaching epistemic practices argue that there has been too much emphasis on models of expert practice and that the goal for science education should not necessarily be for students to conduct investigations in their classroom like professional scientists (Barzilai & Chinn, 2018; Russ, 2014). The goal of apt epistemic performance addresses this by emphasizing that students learn to successfully preform epistemic activities, rather than replicate expert practice (Barzilai & Chinn, 2018). Thus, teaching for apt epistemic performance in a science classroom would help students learn how to perform (or participate in) valued epistemic processes (e.g., collecting and analyzing data) in accordance with epistemic ideals in order to achieve valued epistemic aims (e.g., constructing evidence-based explanations and arguments).

In a classroom, students may not engage in authentic participation to the extent of replicating the practice of an expert scientist. However, students can participate authentically by learning to successfully participate in valued epistemic activities in order to learn science content, as opposed to disjointedly studying content and following experimental procedures. Apt epistemic performance in science means that students are able to reliably participate in scientific processes to understand and successfully construct scientific explanations or models about phenomena that meet the standards generally accepted by the scientific community.

Apt epistemic performance also requires understanding the epistemology of a discipline. To successfully participate in epistemic practice, one needs to recognize and understand the importance of the epistemic aims, ideals, and reliable processes of that community (Barzilai & Chinn, 2018). Barzilai and Chinn describe this understanding as epistemic metacognition. While epistemic cognition refers to the strategic level of epistemic thinking (e.g., evaluating a scientific explanation), epistemic metacognition refers to a higher level of awareness about epistemology and knowledge construction or evaluation (e.g., being aware of and consciously thinking about
the criteria being used to evaluate a scientific explanation). Epistemic metacognition includes understanding the particular ways in which knowledge is constructed and justified within a community, as well as how and why these ways of constructing and justifying knowledge are used (Barzilai & Chinn, 2018; Barzilai & Zohar, 2016). Epistemic metacognition encompasses understanding and recognizing the aims, ideals, and processes of an epistemic practice; how to apply them; and why they are important (Barzilai & Chinn, 2018). In science, this would include understanding, for example: the goal of developing explanations and explanatory models, the criteria and processes used to develop and evaluate explanations, how to successfully apply those criteria and processes, and why those criteria and processes are valued by the scientific community. Thus, apt epistemic performance in science means that students are not just engaging in the practice of science, but they are developing an metacognitive understanding about what they are doing and why they are doing it.

Participation in the practice of a community and understanding the epistemology of that practice are interdependent in the notion of apt epistemic performance. Reliably engaging in processes that achieve epistemic goals is necessary for understanding the significance of and the relationships between the epistemic components of the practice, as well as being able to recognize and monitor when and how to apply these components. Further, epistemic metacognition about an epistemic practice is necessary for successful participation in the practice. This interdependency is central to teaching science in a way that balances students’ engagement in scientific practice/activities with a deeper understanding about how they are participating in efforts of knowledge construction valued by the scientific community.

**Applying the Apt-AIR Framework to Conceptualize Instruction for Science as Epistemic Practice**
The Apt-AIR framework provides a useful lens to conceptualize the epistemic practice of science and helps establish educational goals for students’ learning in science classrooms. However, describing science as epistemic practice and how to teach for apt epistemic performance in science remains fairly abstract. Prior work has shown the utility of applying this lens to analyze students’ participation in and understanding of epistemic practices (Chinn et al., 2014; Chinn, Duncan, Hung, & Rinehart, 2016), but little work has been done to understand teachers’ instruction from this perspective. To ultimately support students’ apt epistemic performance in science, it is important to further characterize science as epistemic practice and provide guidelines for how to teach science in this way. Thus, a key goal of this paper is to apply the Apt-AIR theoretical framework to conceptualize teachers’ instruction with respect to epistemic aims and ideals in science. In doing so, we focus on epistemic aims and ideals, and we address processes as they relate to and help categorize epistemic ideals in science. There can be considerable overlap between epistemic ideals and reliable epistemic processes. There are criteria for successfully engaging in processes, and as processes become well established, they may begin to look more like criteria (personal communication with Chinn, October 6, 2017). In many cases, discussing an epistemic ideal of science also entails discussing epistemic processes. Given this overlap, distinguishing teachers’ instruction about epistemic ideals from reliable epistemic processes would be quite challenging. We focus on epistemic ideals related to four important process: (a) generating questions, (b) planning and conducting investigations, (c) analyzing data, and (d) using evidence. We do not consider this to be an exhaustive list of all the criteria that students should or may need to learn in order to successfully understand and participate in the practice of science. Rather, our goal is to make an initial contribution in this
effort based on a solid foundation of research on science education that can be built upon in future work.

Our work here offers an important contribution by connecting literature from areas of science education and epistemic cognition to make the notions of epistemic aims and epistemic ideals more concrete and contextualized for teaching science. Many of the ideas presented in the Apt-AIR framework have been discussed previously by other researchers, so we draw connections between this work to build on previous recommendations and to conceptualize what epistemic aims and ideals mean in the discipline of science. We use this prior work to highlight how teachers could support their students’ understanding of epistemic aims and ideals in science.

**Epistemic Aims of Science**

As described earlier, epistemic aims are goals to create epistemic products including knowledge, understanding, explanations, and models (Barzilai & Chinn, 2018). A key epistemic aim of science is constructing scientific knowledge and understanding to explain the natural world (Sandoval, 2015). Scientific explanations (e.g., Berland & Reiser, 2009; McNeill, Lizotte, Krajcik, & Marx, 2006; Sandoval & Reiser, 2004) and scientific models (e.g., Nercessian, 2008; Osborne, 2014; Schwarz et al., 2009; Windschitl, Thompson, & Braaten, 2008) are central epistemic products that the scientific community strives to create in order to move the field’s understanding about natural phenomena forward. Prior research on supporting students’ understanding about scientific knowledge construction has highlighted differences in understanding about professional scientists’ and students’ own endeavors in science (Sandoval, 2005; 2014). From a situated perspective of practice, understanding what “scientists do” may not help students understand the epistemic nature of their own work in a science classroom (Sandoval, 2005). Work by Sandoval and others suggests that students’ reasoning about
epistemic ideas is context specific: students reason differently when they are asked general, abstract questions about science and when they are asked questions related to their their scientific inquiry in a particular situation (Sandoval, 2005; 2014; 2015). Sandoval (2005) describes students’ ideas about their own efforts to construct scientific knowledge as “practical epistemologies” and distinguishes these from “formal epistemologies” about professional science.

**Implications for teaching.** From this perspective, teachers might need to provide instruction that helps students understand the epistemic goals of the particular activities in which they engage in their science classrooms. This would involve (a) designing activities centered on creating epistemic products to achieve epistemic aims (e.g., engaging students in constructing scientific explanations and models of phenomena); and (b) helping students recognize the goals of knowledge construction for an activity. As described by Barzilai and Chinn (2018), apt epistemic performance requires developing metacognitive knowledge about the epistemic aims of a practice, which “involves understanding of why particular aims are important, what they entail, what it takes to achieve them” (p. 18). Research on developing epistemic cognition and metacognition has suggested that explicit reflection is key (Buehl & Fives, 2016; Lunn Brownlee et al., 2017; ). Thus, teachers intentionally prompting discussion about the epistemic goal or purpose of an activity may be crucial for helping students recognize and reflect on why they are doing what they are doing and develop the metacognitive knowledge to understand epistemic aims in science. However, it is not clear whether and how teachers discuss the epistemic aims of particular classroom activities with their students. How do teachers help students think about why they are doing what they are doing in science? Additionally, are teachers actively thinking and intentional about having such discussions with students? More research on how teachers
discuss and think about epistemic aims in their classrooms is needed to answer these open questions.

**Epistemic Ideals of Science**

The scientific community engages in a variety of processes that are guided by agreed-upon criteria to construct and evaluate epistemic products (e.g., scientific explanations and models). The epistemic ideals of science can be understood as the criteria or standards that the scientific community uses to create explanations and models and to evaluate the quality of others’ explanations and models. Students need to understand these standards in order to successfully participate in the practice of science. In conceptualizing teachers’ instruction about science as epistemic practice, we focus on epistemic ideals and categorize these ideals based on particular epistemic processes of science. We focus on four broad categories of epistemic ideals in science related to: (a) generating questions, (b) planning and conducting investigations, (c) analyzing data, and (d) using evidence. We draw on prior literature in science education to describe the ideals related to each of these categories and to conceptualize how a teacher might help students understand the criteria for developing or evaluating epistemic products (scientific explanations or models) in science, including what the criteria are and why, when, or how to apply them (Barzilai & Chinn, 2018).

**Generating questions.** Scientific research and knowledge construction are driven by questions (Osborne, 2014). Asking questions and identifying the questions one desires to answer is a fundamental part of science. According to Chin and Osborne (2008) “the formulation of a good question is a creative act, and at the heart of what doing science is all about” (p. 1). Their review of research on students’ questions emphasizes the important role that students’ question play in learning science and engaging in scientific inquiry (Chin & Osborne, 2008). Research on
students’ ability to write questions in science suggests that students’ learning and sustained interest in pursuing investigations is driven by the types of questions they ask, highlighting the importance of teaching students how to write good questions (Chin & Chia, 2004). In order to conduct an investigation and construct knowledge, questions should be researchable or testable (Chin & Osborne, 2008; Lehrer & Schauble, 2015). Chin and Kayalivizhi (2002) describe investigable questions as explanation-seeking, relationship (i.e. comparison, cause-and-effect, pattern-seeking), exploratory, and problem-solving questions. Questions framed as “how” or “why” questions are often more amenable to investigation (Chin & Osborne, 2008). These types of questions focus more on developing explanations or relationships between variables and are considered higher-level questions than “yes” or “no,” fact and basic information seeking questions (Chin & Kayalivizhi, 2002; Chin & Osborne, 2008). Given that an epistemic aim of science is to construct explanations, questions that prompt constructing an explanation rather than finding a “yes” or “no” answer are better aligned with this aim and are more productive for developing new understanding.

Implications for teaching. Teachers could help students understand these epistemic ideals for generating questions by demonstrating and discussing how to write researchable or testable questions that are directed at explaining a phenomena and may start with words like “how” and “why.” Providing instruction about the important features, examples, and non-examples of researchable science questions has been shown to help middle school students improve their understanding of and ability to write questions (Cuccio-Schirripa & Steiner, 2000). Modeling how to ask and write questions can also be an effective way for teachers to help students learn to generate researchable scientific questions (Chin & Osborne, 2008; Allison & Shrigley, 1986). For example, a teacher could model for students how to rewrite a shallow, “yes” or “no” question
into a deeper, “how” or “why” question. This would first present students with a non-example and then highlight important features of productive questions as the teacher helps students create a positive example. Additionally, prior work has shown relationships between the quality of students’ questions and the student-centered, constructivist, and inquiry-based nature of classroom learning environments. As described by Chin and Osborne (2008), the type of instruction teachers use in their classrooms can support students’ abilities to ask and write high-level questions for research and experimentation (Hofstein, Shore, & Kipnis, 2004; Marbach-Ad & Sokolove, 2000). Teachers creating classroom environments in which students’ questions are valued and drive investigations may help students learn the role that questions play in science and how to construct useful questions.

Open questions remain about the extent to which teachers help their students understand criteria for developing researchable or testable questions in science. How do teachers create opportunities for students to generate research questions? How do they help students understand what constitutes a “good” question in science and the central role that questions play to drive investigations in the scientific community?

**Planning and conducting investigations.** Investigations are central to science. The scientific community follows standards for how to set up and conduct investigations in the pursuit of developing scientific explanations and models. Scientific investigations are typically designed to purposefully answer a question or to test a hypothesis or prediction. Just as questions drive scientific investigations (Chin & Osborne, 2008), investigations are designed to pursue specific questions. Thus, in setting up an investigation, deciding what data to collect and how best to collect it should align with the question one is trying to answer. Successfully conducting investigations also involves making strategic decisions that allow one to draw conclusions at the
Experimentation is often considered the goal standard of scientific investigation (Zimmerman, 2007) and involves systematically isolating variables and manipulating only one variable at a time in order to draw conclusions about relationships between variables (Kanari & Millar, 2004; Lehrer & Schauble, 2015; NRC 2012). To this end, much of the work in science education on setting up and conducting investigations has focused on controlling variables (Kuhn, Iordanou, Pease, & Wirkala, 2008). Controlling variables is an important strategy for students to learn because it is a key strategy that directs experimentation and allows valid inferences to be made in science (Klahr, 2000). Manipulating more than one variable at a time makes determining the cause of an outcome unclear, leads to confounded experiments, and prevents knowledge construction (Zimmerman, 2007).

**Implications for teaching.** One step towards helping students understand that how they set up and conduct an investigation should purposefully align with a question they are trying to answer would be first helping them recognize the question they are trying to answer in an investigation, whether that be an experiment or a second-hand research investigation. With a particular question in mind, students might then need guidance to design an investigation that could address that question. For an experiment, this might involve discussing or modeling how to plan trials to test a particular hypothesis or prediction. Teachers can also support students to learn criteria for conducting experiments by modeling how to control variables and strategically manipulate variables. There is substantial evidence that students tend to manipulate more than one variable at a time in experiments and struggle to make decisions about which variables to keep constant or manipulate (Kuhn & Dean, 2005; Zimmerman, 2007). Students are able to develop successful experimentation skills, but often need instruction to adopt this strategy (Zimmerman, 2007). Zimmerman’s (2007) review of research on students experimentation skills
highlights evidence that brief direct instruction about variables and isolating variables can help students learn to control variable and adopt this strategy, as can frequent practice without direct instruction.

Further, teachers likely need to discuss the importance of these standards for experimentation, including why and how these strategies work, to help students develop a metacognitive knowledge about these epistemic ideals. In their investigation of the strategies students used to identify which combination of colorless liquids would produce a color change, Kuhn and Phelps’s (1982) suggest that metacognitive understanding about how and why controlling variables is a successful strategy is important for students to adopt this strategy. Helping students understand reasons for being thoughtful and purposeful in their investigations seems crucial in teaching them to successfully participate in science. While research has investigated the strategies that students employ to control and manipulate variables, it is still not clear how teachers help students to be purposeful in their design and execution of scientific investigations.

**Analyzing data.** Another critical step in the pursuit of constructing knowledge in science is analyzing and interpreting the data collected in order to explain what happened in an investigation. Again, the scientific community has shared norms and standards for how to make sense of data. Scientists analyze and interpret data by identifying variables of interest and looking for relevant patterns and relationships between them (Kuhn et al., 2008; Hug & McNeill, 2008; Lehrer & Schauble, 2015; Sandoval & Reiser, 2004). For instance, in an experiment, one might look at how manipulating an independent variable affected a dependent variable. In non-experimental investigations, one might look for patterns between variables over time such as whether or how particular variables change together. Regardless of the type of investigation, a
key step is deciding what data is important and should be used as evidence, and examining that
data for patterns or trends to draw conclusions (Hug & McNeill, 2008). In doing this, scientists
need to analyze data systematically, take into account all of the data rather than only data that
supports their hypotheses, and avoid bias in their interpretations (Kanari & Miller, 2004).

Implications for teaching. Analyzing and understanding data is challenging for students.
As discussed by Hug and McNeill (2008), prior research shows that students have difficulties
determining what data can and should be used as evidence (McNeill & Krajcik, 2007),
identifying patterns or trends in data (Schauble, Glaser, Duschl, Schulz, & John, 1995), and
drawing conclusions from data. Students often impose patterns on data based on their own
expectations and have trouble making sense of data that does not agree with their hypotheses
(Kanari & Miller, 2004). Students are more likely to identify covariation relationships between
variables (e.g., as one variable goes up, a second variable goes down) but struggle to understand
more complex or non-linear relationships (Kanari & Miller, 2004; Zimmerman, 2007). Teachers
could support students to analyze data by discussing or modeling how to look for patterns and
relationships in their data in order to understand what happened in their investigation. Giving
students opportunities to analyze complex data sets can encourage conversations about how to
manipulate, graph, and find patterns in data (Hug & McNeill, 2008). Utilizing visualizations and
visual cuing to direct students attention to particular features have been also shown to help
students’ reasoning (Vendetti, Matlen, Richland, & Bunge, 2015) and are strategies that could be
used by teachers to support their students. Drawing students attention to particular variables in a
data table and asking guiding questions to help students make connections and see relationships
are instructional moves that might support students in analyze and interpret data.
More research is needed to understand whether and how teachers effectively help students analyze and interpret data in their classrooms. Providing opportunities to graph and analyze data may occur in classrooms, but open questions remain about the extent to which teachers support and engage students in conversations about *how* to actually make sense of patterns and relationships so students are then able to effectively use data to develop explanations.

**Using evidence.** Finally, we focus on epistemic ideals of science related to using evidence. The scientific community holds high standards for using evidence, because the construction of scientific knowledge often rests on the use of evidence. In developing scientific explanations and models about phenomena, evidence plays a central role in supporting the claims being made and in convincing others about the ideas presented in explanations and models. Extensive literature on scientific argumentation highlights the importance of using evidence to justify claims and convince or persuade others of an argument (Berland & Reiser, 2009; Driver Newton, & Osborne, 2000; Osborne, 2010; Sampson & Clark, 2010; Toulmin, 1958). Much of the work on constructing scientific explanations also emphasizes the importance of supporting explanations with appropriate evidence (Berland & Reiser, 2009; McNeill et al., 2006; Sandoval & Reiser, 2004). While there are different perspectives in the literature on distinctions between scientific argumentations and explanation (Berland & McNeill, 2012; Berland & Reiser, 2009, Braaten & Windschitl, 2011; Osborne & Patterson, 2011), researchers often agree that using evidence to support ideas and convince others are important standards in science.

While we do not intend to delve into the theoretical and philosophical distinctions between scientific explanation and argumentation here, we do wish to highlight a few important points to help clarify our focus on the role of using evidence (see Berland & McNeill, 2012;
Braaten & Windschitl, 2011; and Osborne & Patterson, 2011 for more discussion of these differences). A major distinction drawn between scientific explanation and argumentation is that the purpose of explanation is to provide an explanatory account of a phenomena and that the purpose of argumentation is to convince an audience of a claim (Berland & McNeill, 2012; Osborne & Patterson, 2011). Explanation focuses on the epistemic goal of understanding and constructing knowledge about how and why things occur; argumentation focuses on the persuasion and use of evidence to convince others of an explanation, highlighting the social construction of knowledge in science (Berland & McNeill, 2012). From the perspective of scientific argumentation, the quality of an explanation or model is often determined by how evidence is used to support the idea. Braaten and Windschitl (2011) argue that using evidence is a criteria of argumentation and not a defining characteristic of an explanation, even though using evidence is often discussed in science education literature on explanations. In an argument, evidence can be used to support a claim that is not actually explanatory. However, while using evidence is not what makes a statement explanatory, Braaten and Windschitl (2011) do agree that using evidence is an important criteria for supporting explanations and convincing others of explanations. Thus, we focus on the use of evidence in supporting explanations and claims (that may be more descriptive than explanatory) and in convincing others of explanations and claims.

**Implications for teaching.** The substantial prior research on constructing scientific explanations and arguments provides guidance for instructional practices to help students understand the epistemic ideals about using evidence in science (e.g. Lu & Lajoie, 2008; McNeill & Krajcik, 2008; Sandoval & Reiser, 2004; Songer, Fick, & Shah, 2012; Zohar & Nemet, 2002). Across this literature, a common suggestion is to provide scaffolds that help students structure explanations and arguments to see where and how to incorporate evidence.
One example of this support comes from Sandoval and Reiser’s (2004) work on an online tool for supporting students’ construction and evaluation of scientific explanations. ExplanationConstructor provided organization and structure that helped scaffold students to analyze data and construct explanations of phenomena based on that data. Their findings showed that such structure helped students construct better explanations. McNeill and colleagues (2006) also found benefits of using written instructional materials to provide, and then fade, generic prompts to help students understand the different components of an explanation (claim, evidence, reasoning) and content specific prompts to help students think about what information to include in their explanations. McNeill and Krajcik (2008) further investigated the instructional moves of 13 middle school science teachers and found that defining the components of a scientific explanation, modeling how to construct an explanation, and explicitly discussing the rationale of scientific explanation helped improve students’ written explanations. Their results showed that explicitly discussing the rationale to convince or persuade an audience about a claim had the greatest effect on improving students explanations. In fact, defining the necessary components of an explanation (that it include a claim, evidence, and reasoning) was only beneficial for students with the teacher also discussed the rationale. These findings support the idea proposed by the Apt-AIR framework that students need to develop metacognitive knowledge about why criteria are important in order to achieve apt epistemic performance.

While prior work has discussed the centrality of evidence in science and the importance of helping students understand how and why to use evidence, questions still remain about how teachers frame the use of evidence as an integral aspect of scientific practice. For instance, how do teachers talk about the use of evidence in relation to the driving question students are trying to answer in an investigation? How do teachers help students understand the relationship between
how they designed an experiment, the data they collected, and how that data could be used as
evidence to support a claim? Beyond analyzing students ability to use evidence, future research
could look more closely at how teachers support students to understand the role that evidence
plays in the epistemic pursuits of science.

Discussion

Teaching students to understand and successfully participate in the epistemic practice of
science is a vision for science education that requires changes in teachers’ instruction and
reframing classroom activities in terms of the epistemic pursuit of science to build knowledge
and explanations about the natural world. Crucially, teachers need guidance to effectively
implement instruction that aligns with the epistemic nature of practice in the scientific
community (Sandoval, Kawasaki et al., 2016). Our goal in this chapter has been to provide a
conceptual and theoretical basis for developing such guidance. Building on the theoretical
implications of practice and a situated view of learning epistemic practice, we believe that
teachers can support students to learn science as epistemic practice by engaging them in the
authentic, epistemic activities of science and helping students understand how and why certain
ways of participating are valued in science. Conceptualizing science in terms of the epistemic
aims and epistemic ideals of the scientific community further specifies aspects of scientific
practice that students need to understand in order to knowledgably and successfully participate
(i.e., to achieve apt epistemic performance).

Our work extends understanding about teaching science as epistemic by bringing a new
lens focused on epistemic practice to existing research in science education. The Apt-AIR lens
helps to conceptualize how students can participate in the authentic work of science in a
classroom and what specific epistemic goals and standards of science teachers can help students
learn to support successful participation. Applying the Apt-AIR framework to science teaching provides guidance for the types of activities and instruction needed to help students learn science as epistemic practice. From this perspective, it is important to design activities and curricula that have epistemic aims, such as constructing scientific explanations or models, and that engage students in valued scientific processes to achieve those aims. However, having students construct explanations and models is by no means a new idea in science education given the substantial literature on both (e.g., McNeill & Krajcik, 2008; Schwarz et al., 2009; Windschitl et al., 2008). Using the Apt-AIR lens, though, further highlights why these are important activities for students and emphasizes that students and teachers need to understand this why in order to knowledgably engage in scientific practice: centering classroom science on the construction and evaluation of explanations and models is important because it allows students to participate in the meaningful, epistemic activities of the scientific community and provides a context for developing a scientific community within the classroom. We believe that this framing of activities in terms of epistemic practice is crucial for teachers to understand and use in their classrooms to shift away from students “doing science,” towards participating in and understanding science as a way of explaining, evaluating, and representing the world (Lehrer & Schauble, 2015).

Further, the Apt-AIR lens suggests that it is also important for teachers to talk intentionally with students about the aims of specific activities and the criteria they should follow to construct and evaluate scientific knowledge or explanations. Helping students develop metacognition about why they are participating in particular activities or need to follow certain standards is an essential part of teaching the epistemic practice of science. Being able to writing a evidence-based explanation is great; however, ideally we would want students to use evidence
to support their explanation not because their teacher said so, but because they understand the
role evidence plays in science and why the scientific community values evidence.

An important next step is to investigate how the instruction conceptualized in this chapter
translates to real classrooms. The conceptual and theoretical work presented here lays the
foundation for exploring whether and how teachers support students to understand the epistemic
aims and ideals of science.
CHAPTER 3

Teachers’ Instruction for Understanding and Participating in Science as Epistemic Practice

There is increasing emphasis in science education and reform on engaging students in the practice of science (Lehrer & Schauble, 2015; National Research Council, 2012). Teaching students to participate in and understand science as an epistemic practice of developing explanations and understanding about phenomena calls for integrating the ways in which the scientific community builds knowledge with those of classrooms (Berland et al. 2016). Teaching science with a focus on epistemic practice is a large change from common instructional approaches that presents challenges for many teachers and requires additional support for teachers (Elby, Macrander, & Hammer, 2016; Davis, 2003; McNeill & Knight, 2013; Sampson & Blanchard, 2012; Sandoval, Kawasaki, Cournoyer, & Rodriguez 2016). As efforts increase to help teachers enact this change, there is a need to better understand and develop instructional recommendations for teaching students to successfully participate in the epistemic practice of science. Identifying instructional practices that support student learning is an essential step in being able to design tools and learning opportunities that prepare teachers to provide such support (Windschitl, Thompson, Braaten, & Stroupe, 2012).

To achieve the goal of students learning to participate in scientific practice, it is crucial to understand how teachers can effectively build science communities within their classrooms through instruction that aligns with the epistemic practice of science. Teachers play a critical role in how and what students learn in a classroom (Remillard, 2005). While curricula and learning materials are important, teachers influence how those materials are actually enacted (Remillard, 2005). It is well documented that teachers’ instructional practices have important influence on students’ participation in aspects of scientific practice (e.g., McNeill & Krajcik, 2008; Songer,
Fick, & Shah, 2012; Windschitl et al., 2012). Additionally, when it comes to teaching about the epistemology of a community or discipline, the epistemic environment that teachers create (that is, the way they frame the construction of knowledge and understanding) in the classroom has been shown to influence students’ learning and epistemic cognition (Buehl & Fives, 2016).

Currently, there are minimal instructional guidelines for teaching science as practice (Hanuscin & Zangori, 2016), especially that are strongly and clearly aligned with the epistemological foundations of science. We do not know much about how teachers provide instruction that reflects or frames science in their classrooms as epistemic practice and how such instruction might relate to students’ understanding of and ability to participate in science as epistemic practice. To help teachers implement a focus on practice in their classrooms, we first need to better understand and define effective instruction that is aligned with the epistemic practice of science. Being able to identify instruction that aligns with this perspective will be instrumental for establishing recommendations for instructional practices teachers can use to build scientific communities in their classrooms and support students’ participation in science.

We have focused in this work specifically on teachers’ instruction about the epistemic goals of science and the criteria established by the scientific community to pursue these goals. Epistemic goals and criteria, also known as epistemic aims and epistemic ideals, are central aspects of epistemic practice (Chinn & Rinehart, 2016; Chinn, Rinehart, & Buckland, 2014) and are essential to understand in order to successfully participate in the epistemic practice of a particular community (Barzilai & Chinn, 2018). Our goals in this paper were two fold. First, we wanted to better understand what teachers’ instruction for science as epistemic practice, conceptualized in the previous chapter in terms of the epistemic aims and ideals of science, actually looked like in classrooms and to identify trends in how teachers approached teaching in
this way. Second, we aimed to investigate how teachers’ instruction about the epistemic aims and ideals of scientific practice related to students’ understanding of and ability to participate in valued epistemic activities in a classroom.

This paper is organized as follows: first, we discuss our theoretical basis for analyzing teaching science as epistemic practice, drawing on a situated perspective of learning practice and the Apt-AIR framework proposed by Barzilai and Chinn (2018). We then describe the research questions, methods, and findings of our study. We conclude by discussing the implications of this work for teaching science as a connected effort to develop explanations about the world.

Theoretical Framework

Epistemic practices are the established and often discipline specific ways in which communities develop knowledge and understanding (Sandoval, Greene, & Bråten 2016). Viewing science as epistemic practice emphasizes the ways in which the scientific community constructs knowledge and aims to explain natural phenomena. Rather than viewing science as methodology or a body of knowledge, framing science as epistemic practice highlights that science is an ongoing effort to develop explanations about the natural world and continually evaluate those explanations (Berland et al., 2016; Lehrer & Schauble, 2015; Stroupe, 2015). Rooted in a sociocultural and situated perspective, learning an epistemic practice entails authentically participating in the practice and being knowledgeable about how the different norms, processes, and activities contribute to the knowledge building effort (Lave & Wenger, 1991; Wenger, 1998).

Based on this perspective, scholars have discussed what it means for students to learn the practice of the a community in classrooms. That is, what counts as authentic and knowledgeable participation in a classroom? Rather than striving to replicate the expert practice of professional
scientists in classrooms, prior work has argued for a focus on students learning to productively construct knowledge in science (Berland et al., 2016; Russ, 2014; Stroupe, 2015). As Berland and colleagues (2016) have described, “meaningful engagement” in scientific practice in a classroom requires “merging” the “epistemic goals and ways of knowledge building” held by the classroom and the scientific community. The goal for students learning an epistemic practice can seen as a goal for students to engage successfully and reliably in the valued processes of a community to develop epistemic products (i.e., knowledge, understanding, explanations), what Barzilai and Chinn (2018) have termed *apt epistemic performance*. Importantly, apt epistemic performance is attributed to students’ ability and understanding of what they are doing. This perspective suggests that to help students learn the epistemic practice of science, teachers would need to support participation in authentic activities of the scientific community *and* to help students understand how and why these activities are important to the community. Teaching science as epistemic practice calls for teachers to shift the ways of building knowledge in their science classrooms to more closely align with the ways of building knowledge in the scientific community. To support this shift, it is important to understand how teachers’ instruction can frame science activities and knowledge construction in this way in their classrooms. In our work, we use the goal of teaching for apt epistemic performance and the theoretical framework from which it was derived, described next, as a lens to understand how teachers’ instruction could support students’ learning science as practice.

**The Apt-AIR Framework as Lens for Science Teaching**

We apply the theoretical conceptualizations of epistemic practice and apt epistemic performance proposed by Barzilai and Chinn (2018) in the Apt-AIR framework to identify and understand how teachers’ instruction aligns with learning science as epistemic practice.
Developed from the work of Chinn and colleagues (Chinn & Rinehart, 2016; Chinn, Rinehart, & Buckland, 2014), this framework utilizes a sociocultural perspective to describe an epistemic practice as the combination of the epistemic aims, epistemic ideals, and reliable epistemic processes of a community (described more next). In applying the Apt-AIR framework to analyze how teachers’ instruction aligned with the epistemic practice of science, we focus on epistemic aims and ideals, and we address processes as they relate to and help categorize epistemic ideals in science. As described more later, there are strong connections between epistemic ideals and reliable epistemic processes (personal communication with Chinn, October 6, 2017), and discussing an epistemic ideal of science often entails discussing epistemic processes. Given this overlap, distinguishing teachers’ instruction about epistemic ideals from reliable epistemic processes would be quite challenging.

*Epistemic aims* are goals to construct epistemic products, including knowledge, understanding, explanations, and models (Barzilai & Chinn, 2018). The epistemic aims of science are the goals of the scientific community to build knowledge, understanding, and explanations about the natural world (Sandoval, 2015). Constructing scientific explanations (e.g., Berland & Reiser, 2009; McNeill, Lizotte, Krajcik, & Marx, 2006; Sandoval & Reiser, 2004) and scientific models (e.g., Nercessian, 2008; Osborne, 2014; Schwarz et al., 2009; Windschitl, Thompson, & Braaten, 2008) are central to this effort. Helping students understand science as epistemic practice entails helping them understand the goals of science to construct explanations and explanatory models. Rather than talking with students about the goals of scientists in general, a situated perspective of learning practice suggests that students should be helped to understand the epistemic goals of their *own* work in a science classroom (Sandoval, 2005). Therefore, in investigating how teachers support students to understand science as epistemic practice, it is
important to understand how teachers talk to their students about the epistemic aims of the specific science activities they are doing in the classroom.

*Epistemic ideals* are the criteria or standards held by a community for developing or evaluating epistemic products (Barzilai & Chinn, 2018). The epistemic ideals of science can be understood as the criteria or standards that the scientific community uses to create explanations and models and to evaluate the quality of others’ explanations and models. The Apt-AIR framework suggests that students would need to understand these standards in order to successfully participate in the practice of science. This includes, for example, standards for how to conduct a investigation or experiment and use evidence to support claims. In conceptualizing teachers’ instruction about science as an epistemic practice, we focus on epistemic ideals and categorize these ideals based on particular epistemic processes of science. *Reliable epistemic processes* are the ways and procedures used (in accordance with particular criteria) by a community to develop knowledge and understanding. For science, these processes include asking questions, conducting investigations, analyzing and interpreting data, and constructing evidence-based arguments. While these processes are often described as “science practices,” we think of them as a set of epistemic processes that make up the overarching practice of the scientific community.

We focus on four broad categories of epistemic ideals in science related to: (a) generating questions, (b) planning and conducting investigations, (c) analyzing data, and (d) using evidence. Prior research has highlighted ideals and criteria for successfully participating in these four aspects of scientific practice. Ideals for generating questions in science include that questions should be researchable or testable and that “how” or “why” questions focused on developing explanations or relationships between variables are considered higher-level than “yes” or “no,”
basic information-seeking questions (Chin & Kayalivizhi, 2002; Chin & Osborne, 2008; Lehrer & Schauble, 2015). Standards for conducting investigations in science include setting up investigations to purposefully test a hypothesis or answer a question and to isolate or manipulate only one variable (Kanari & Millar, 2004; Lehrer & Schauble, 2015; NRC 2012; Zimmerman, 2007). To analyze and interpret data, the scientific community typically identifies variables of interest and looks for relevant patterns and relationships between them (Kuhn, Iordanou, Pease, & Wirkala, 2008; Hug & McNeill, 2008; Lehrer & Schauble, 2015; Sandoval & Reiser, 2004). Whether an experiment or a non-experimental investigation, one must decide what data is important and should be used as evidence, and examine that data for patterns or trends to draw conclusions (Hug & McNeill, 2008). Finally, the scientific community holds high standards for using evidence to support explanations and convince others of claims. Research on scientific argumentation highlights the importance of using sufficient evidence to justify claims and convince or persuade others of an argument (Berland & Reiser, 2009; Driver et al. 2000; Osborne, 2010; Sampson & Clark, 2010; Toulmin, 1958). Much of the work on constructing scientific explanations also emphasizes the importance of supporting explanations with appropriate evidence (Berland & Reiser, 2009; McNeill et al., 2006; Sandoval & Reiser, 2004).

**Relationships between Epistemic Aims, Ideals, and Processes**

Science is a practice that has particular epistemic aims that are pursued by the community, and the processes by which those aims are achieved are guided by particular epistemic ideals. Learning these goals, norms, and standards for how to participate in the practice of a community is about enculturation into the community (Shaffer, 2017). Quantitative ethnography is a theory that enculturation is about understanding connections and associations between the norms, knowledge, skills, and ways of building knowledge in that community (Shaffer, 2017). What is
important about learning the practice of a community – their ways of thinking and making meaning – is understanding these connections and associations (Shaffer, 2006; 2017; Shaffer, Collier, & Ruis, 2016). Bringing this theory of enculturation in conversation with the Apt-AIR framework about learning epistemic practice, what is important about learning epistemic practice is understanding the connections between epistemic aims, ideals and reliable process. Applying the perspective of quantitative ethnography to the Apt-AIR framework highlights the importance of focusing on these connections. This approach aligns with Chinn and colleagues’ discussions about the connected nature of epistemic aims, ideals, and reliable processes (Chinn, Buckland, & Samarapungavan, 2011; Chinn et al., 2014; Chinn & Rinehart, 2016), but goes a step further to bring these connections to the forefront.

Chinn and colleagues have described the epistemic aims, ideals, and reliable processes of an epistemic practice as connected and used together to create and evaluate epistemic products (Chinn et al., 2014; Chinn & Rinehart, 2016). Epistemic aims and ideals are related in that an epistemic aim of a practice is often to achieve the epistemic ideals of that practice (personal communication with Chinn, October 6, 2017). In science for example, the scientific community generally agrees that explanations should meet certain criteria, and achieving the epistemic aim of constructing a scientific explanation requires meeting those criteria. Similarly, reliable epistemic processes are related to epistemic ideals in that reliable processes are the procedures used by a community to meet epistemic ideals (and subsequently reach epistemic aims). For example, analyzing data (process) is necessary in order to include evidence for a claim (ideal) in a scientific explanation (aim). As processes become well established, they may even begin to look more like ideals. This idea can be illustrated by the use of evidence in science. Using evidence to support a claim can be considered a reliable epistemic process—that is, a valued
procedure used to construct a scientific explanation. However, this process is well established in the scientific community and is also often seen as a criterion of a good scientific explanation. At a certain level of expertise, the connections between aims and ideals and processes can be so strong that it is challenging to distinguish them (personal communication with Chinn, October 6, 2017). While these relationships between epistemic aims, ideals, and processes have been mentioned elsewhere, that these connections are essential to defining the epistemic practice of a community has not been central. We see applying the lens of quantitative ethnography to highlight these connections as an important contribution for understanding teachers’ instruction for science as epistemic practice.

From this perspective, helping students learn the epistemic practice of science entails helping them understand the connections and relationships between aspects of scientific practice. A goal of science teaching, thus, should be to present science in a way that reflects these connections and how aspects of scientific practice are interdependent in the effort to explain the natural world. To help students understand how criteria related to certain processes contribute to achieving epistemic goals, it would be important for teachers to discuss ideas about epistemic aims and ideals in relation to each other. From the perspective of quantitative ethnography, characterizing teachers’ instruction is not just about identifying what is said but also understanding how the ideas discussed are connected (Shaffer, 2017). In our investigation of teachers’ instruction this paper, we use analysis tool developed for quantitative ethnography, Epistemic Network Analysis (ENA, Shaffer et al., 2016), to model the connections that teachers make between the epistemic aims and ideals of science in their instruction. With this tool (discussed more in the methods), epistemic aims and ideals can be modeled as the nodes in a network that are connected in particular ways based on the temporal relationships between what
teachers say, allowing us to identify and quantify these connections (Shaffer et al., 2016). We believe that efforts to understand how teachers frame science as epistemic practice and support communities of scientific practice in their classrooms are well suited for and could greatly benefit from such analysis.

The Present Study

Our study addresses the issue of how teachers support their students to learn science as epistemic practice in classrooms. In particular, we examined teachers’ approaches to teaching about the epistemic aims and ideals of science, and how this instruction related to students’ understanding and ability to participate in the practice of science. We aimed to answer the following research questions:

• How do teachers provide instruction for understanding science as epistemic practice?
  o Specifically, how do teachers provide instruction directed at helping students understand the epistemic aims and epistemic ideals of science?

• How do patterns of teachers’ instruction relate to students’ understanding of science as an epistemic practice and ability to participate in valued epistemic activities of science?

To answer these questions, we investigated how five teachers using the same curriculum discussed ideas about the epistemic practice of science with their students and how differences in their instruction corresponded to students’ understanding.

Methods

Participants

The participants in this study were five 8th grade science teachers – Mr. C, Mrs. S, Mr. P, Mrs. J, and Mrs. M— and the students in one of their science classes (all teacher and student names are pseudonyms). The teachers were from three public middle schools in a Midwestern
United States city. The teachers differed in years of science teaching experience (ranging from one to 14 years), and the schools differed slightly in demographics (see Table 1). The teachers were recruited as participants in a larger research project through which they taught design-based, inquiry science curricula, discussed next.

While each teacher taught multiple science classes, one target class for each was selected for video recording, and we included students from these target classes in our study (N=111 total students). Target classes were chosen based on teachers’ guidance about representative classes of average academic ability and logistical constraints of the research team. All students in the classes participated in all aspects of the curriculum, but student data was only collected from consenting students. This resulted in n=28 students for Mr. C, n=15 for Mrs. S, n=22 for Mr. P, n=23 for Mrs. J, and n=23 for Mrs. M.

Table 1

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Years Teaching Science</th>
<th>School</th>
<th>School demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. C</td>
<td>14</td>
<td>School A</td>
<td>- 66% white, 19% Hispanic, 6% black</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- 59% economically disadvantaged</td>
</tr>
<tr>
<td>Mrs. S</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mr. P</td>
<td>12</td>
<td>School B</td>
<td>- 78% white, 10% Hispanic, 5% black</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- 44% economically disadvantaged</td>
</tr>
<tr>
<td>Mrs. J</td>
<td>10</td>
<td>School C</td>
<td>- 70% white, 13% Hispanic, 7% black</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- 63% economically disadvantaged</td>
</tr>
<tr>
<td>Mrs. M</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Context

Teachers taught a 12-week design-based life sciences unit on energy and matter transformation in ecosystems. The unit presented students with a design challenge to create
compost that broke down quickly and contained nutrients to help address the global issue of increasing amounts of waste in landfills. Each activity in the unit engaged students in scientific practice to learn relevant content to solve this challenge. The curriculum was designed to pursue epistemic aims in science of building scientific explanations about energy transformation and matter cycling in compost and evidence-based arguments about why students’ compost designs would help address their problem. These activities consisted of whole-class and small-group discussions through which students developed research questions, conducted experiments and second-hand research investigations, analyzed data, constructed scientific explanations, and developed arguments about how to solve their challenge. For students to successfully solve their challenge in this unit, it was important for them to understand the overarching goals and purposes (epistemic aims) of activities and the criteria (epistemic ideals) for participating in scientific practice to achieve those goals.

As part of the larger research project, all teachers participated in professional development about implementing the curriculum and facilitating student-centered, inquiry-based approaches to science. This professional development was not directed at developing knowledge of or instructional strategies specifically about the epistemic aims or ideals of science that were analyzed in this study. Thus, this was not a study of teachers’ uptake of instructional strategies, but rather an investigation into their current approaches.

**Data Sources**

We used several data sources to investigate teachers’ instruction and students’ apt epistemic performance. To investigate teachers’ instruction, we used classroom videos to look at the connections teachers made between epistemic aims and ideals and their discussions of epistemic aims and ideals over time. To investigate students’ apt epistemic performance, we used
written responses about how scientists convince others of their explanations as a measure of students’ understanding, and we used students’ data charts and written explanations after an experiment as a measure of students’ participation in the epistemic practice of science. These data sources (next) and corresponding analyses (described later) are summarized in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Construct</th>
<th>Data Source</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teachers’ Instruction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connections between</td>
<td>Classroom videos of</td>
<td>Epistemic Network Analysis (Shaffer, Collier, &amp; Ruis, 2016) of connections teachers made between epistemic aims and ideals</td>
</tr>
<tr>
<td>epistemic aims and ideals</td>
<td>teachers’ instruction</td>
<td></td>
</tr>
<tr>
<td>Discussion of epistemic</td>
<td>Classroom videos of</td>
<td>Chronological representations (Luckin et al., 2001; Hmelo-Silver, 2003) of teachers’ talk about epistemic aims and ideals over time</td>
</tr>
<tr>
<td>aims and ideals over duration of</td>
<td>teachers’ instruction</td>
<td></td>
</tr>
<tr>
<td>unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>**Students’ Apt Epistemic</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students’ understanding of the</td>
<td>Students’ post-unit response to: “How do scientists convince other people</td>
<td>Epistemic Network Analysis (Shaffer et al., 2016) of connections students made between various epistemic ideals or processes</td>
</tr>
<tr>
<td>epistemic practice of science</td>
<td>about their explanations of why things happen the way they do in the world</td>
<td></td>
</tr>
<tr>
<td></td>
<td>around us?”</td>
<td></td>
</tr>
<tr>
<td>Students’ participation in the</td>
<td>Students’ data charts and written scientific</td>
<td>ANOVA and post-hoc pairwise comparisons of students’ ability (between teachers) to apply epistemic ideals to conduct experiment, analyze and interpret data, and use evidence</td>
</tr>
<tr>
<td>epistemic practice of science</td>
<td>explanations from an experiment</td>
<td></td>
</tr>
</tbody>
</table>

**Teachers’ instruction.** We used classroom videos of the five teachers implementing the compost unit in one of their science classes as evidence of their instructional practices, specifically their approaches to helping students understand science as an epistemic practice. The videos captured the teachers introducing and providing instruction about the various activities
within the unit, and facilitating whole-class and small-group discussions with students during the activities. When students were working in their small groups, the videos followed the teacher moving between groups.

We used videos of selected lessons in which students were preparing for, conducting, and developing scientific explanations based on investigations. These selected lessons occurred during the middle of the unit, spanning two to three weeks, and specifically captured teachers’ interactions with students as they: (a) developed research questions about factors that influence decomposition; (b) conducted research with an online e-text to gather information to answer their questions; (c) conducted four experiments using a virtual compost simulation to investigate how several biotic and abiotic factors affect decomposition (including moisture content, carbon to nitrogen ratio, and the size of the particles); and (d) used their findings to revise the conditions in their physical compost bins and to develop and explain their recommendations for designing a successful compost. The videos total approximately 36 hours: 7.5 hours for Mr. C, 7 hours for Mrs. S, 7.3 hours for Mr. P, 7 hours for Mrs. J, and 7 hours for Mrs. M.

These lessons were selected because they reflected key cycles of epistemic practice in science: planning and conducting investigations in order to construct scientific explanations and understanding. These lessons engaged students in epistemic processes (e.g., generating research questions, planning an experiment, controlling variables, systematically analyzing data) with the goal that students would learn to create important epistemic products (scientific explanations and understanding of phenomena) that met criteria agreed upon by the scientific community (e.g., that the explanation is supported by the data). Thus, these lessons provided a context for ample opportunities to see how teachers approached teaching students about epistemic aims and epistemic ideals of science as they engaged in these processes.
We recognize that the instructional practices teachers enact in their classroom are context dependent and result from a complex combination of their knowledge, environmental factors, and social interactions (Remillard, 2005, Windschitl et al., 2012). Thus, we acknowledge that teachers’ actual instruction may not reflect their intended instruction and is only one window into their knowledge (Remillard, 2005; Elby et al., 2016). We used classroom videos of teachers’ instruction as evidence of what was enacted in the classroom, not necessarily as a measure of teachers’ knowledge about science as an epistemic practice or knowledge about pedagogy.

**Students’ apt epistemic performance.** We used students’ performance on two measures to assess (a) students’ understanding of the epistemic practice of science and (b) students’ participation in the epistemic practice of science.

**Students’ understanding of the epistemic practice of science.** First, to assess understanding of the epistemic practice of science, we used students’ responses to a question about how scientists construct and defend explanations. Students wrote these responses at the very end of the compost unit, occurring after the teachers’ instruction analyzed in this study. The question asked: “How do scientists convince other people about their explanations for why things happen the way they do in the world around us?” This question was designed to probe students’ knowledge about how the scientific community pursues the epistemic aims of constructing explanations and understanding. A key goal of science is to develop explanations about phenomena in the world. Members of the scientific community present their explanations to one another, and the community collectively evaluates each other’s explanations and arguments to build better understanding. This question assessed students understanding of how this happens in science, and we used students’ responses as evidence of their understanding about the epistemic nature of scientific practice.
Students’ participation in the epistemic practice of science. Second, to assess students’ ability to participate in aspects of the epistemic practice of science, we used students’ written work in their journals as they conducted an experiment. Students’ journals were designed to be records of their ideas and work throughout the compost unit. Specifically, we used students’ data charts and written scientific explanations in the journals as evidence of their ability to apply epistemic criteria and successfully participate in conducting investigations, analyzing and interpreting data, and using evidence to support claims. During the unit, students conducted three experiments using a computer-based compost simulation to help them learn how abiotic factors influence the rate of decomposition in compost. Students needed to thoughtfully conduct trails in each experiment to understand how each abiotic factor influenced decomposition, analyze their data to make a claim about ideal conditions for decomposition, and use evidence from their experiment to support their claim. We specifically looked at the data charts and “Report Out” pages in the students’ journals for the second experiment focusing on moisture content.

Data charts in the journals were designed with prompts after each trial asking students to provide a rationale for their next trial. This feature was intended to help students think and elicit their reasoning about each trail as building on the previous. The Report Out page of the journal asked students to state their findings from the experiment use evidence from their experiments to construct scientific explanations about their findings throughout the unit. Students wrote these explanations in journals they used to record all of their work throughout the compost unit.

Analysis

Teachers’ instruction. We used a mixed-methods approach to analyze the classroom videos for the instruction teachers provided to help students understand science as an epistemic practice. All videos were transcribed and teachers’ discourse was qualitatively coded, by turns of
talk, for instances of discussing epistemic aims and epistemic ideals of science (described more below). We then investigated differences between teachers in their talk with respect to how they (a) made connections between epistemic aims and ideals and (b) discussed epistemic aims and ideals over the duration of the unit.

Coding scheme. We coded each line of teacher discourse for the presence of talk about epistemic aims and epistemic ideals of science. We developed our coding scheme using both deductive and inductive processes to coordinate between the theory and data. We began with deductive, theoretically motivated codes based on the Apt-AIR framework (Barzilai & Chinn, 2018) and the literature on epistemic aims and ideas discussed previously, and then refined these codes from the data. This resulted in one code for epistemic aims of science and four codes for epistemic ideals of science associated with different processes. Table 3 shows both the theoretically based description for each of our five codes and the applied description in the context of the science unit captured in classroom video data. The curriculum that teachers used in this study was designed to engage students in activities that pursued epistemic aims by participating in processes in accordance with epistemic ideals. Thus, our coding scheme was not intended simply to identify instances of engaging students in these types of activities. Rather, the coding scheme aimed to identify teachers’ instruction (discourse) related to helping students develop the metacognitive knowledge associated with apt epistemic performance: understanding what those aims and ideals are, and when, why, and how to use them in science.
Table 3

**Coding Scheme for Teachers’ Instruction in Classroom Videos**

<table>
<thead>
<tr>
<th>Code</th>
<th>Theoretical Description / Basis for Code</th>
<th>Applied Description in Context</th>
<th>Examples from Data (classroom videos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epistemic aims of science</td>
<td>Teacher discusses with students the goals of activities to construct epistemic products in science, including what the aims are, why, when, or how to apply them (Barzilai &amp; Chinn, 2018). Epistemic goals of specific, contextualized activities (Sandoval, 2005) include: - Construct scientific explanations about natural phenomena, how the world works (Berland &amp; Reiser, 2009; McNeill, Lizotte, Krajcik, &amp; Marx, 2006; Sandoval, 2015; Sandoval &amp; Reiser, 2004) - Construct scientific models that represent and explain particular features of nature (Nercessian, 2008; Osborne, 2014; Schwarz et al., 2009; Windschitl, Thompson, &amp; Braaten, 2008) Discussion of how a specific activity relates or contributes to an overarching epistemic goal of science class or curriculum</td>
<td>Teacher discusses, models, or asks question to help students think about a goal of the activity students are engaged in, such as: - To construct explanations about a phenomena (e.g., decomposition) - To construct models that represent or explain a phenomena (e.g., decomposition) - To explain / understand the science of decomposition - To solve their challenge to create a successful compost Discusses how a specific activity relates or contributes to students’ overarching goal in curriculum</td>
<td>“And remember the purpose of this activity is we’re trying to help ourselves with our challenge, right? We’re trying to figure out which compost is going to make break down fast, and have a lot of nutrients. And so, we really want to spend some time researching about what factors are going to help us help our compost.” “Remember, your overall goal is to find answers to your questions so it can help you with your compost and with our challenge, that’s one of the purposes of our research.” “Your purpose of these questions is A, we are looking for answers, but why do we want answers? What is our overall question? What is the purpose of asking all these questions? I want you to talk in your groups for just a second. Why are we doing this? Why are we doing this research? Why are we asking these questions?” “Wait can I stop you for just a second? So he kind of alluded to it there, what is the purpose of doing these simulations? I’ve got a virtual simulation, why are we doing it?”</td>
</tr>
<tr>
<td>Epistemic ideals of science</td>
<td>Teacher discusses with students criteria or standards for developing or evaluating epistemic products (scientific explanations/models) in science, including what the criteria are, why, when, or how to apply them (Barzilai &amp; Chinn, 2018). Such criteria (sub-categorized) include: - Questions should be researchable or testable in order to conduct an investigation (Chin &amp; Osborne, 2008; Lehrer &amp; Schauble, 2015) - Questions focused on explanations, cause-</td>
<td>Teacher discusses, models, or asks question to help students think about a criteria or standard for a particular process (sub-categorizes) that contributes to creating and evaluating scientific explanations/models: - Writing questions that are researchable or testable - Writing questions that will help gather information needed to</td>
<td>- see examples for each sub-code -</td>
</tr>
<tr>
<td>Generating questions</td>
<td></td>
<td></td>
<td>“How can we create a question from our brainstorm? What are some words that we can use and start with to create those questions? Let me ask you this: should I start a question with “if”?”</td>
</tr>
</tbody>
</table>
| Setting up and conducting an investigation | and-effect, or relationships (how or why) are considered higher-level questions than ‘yes or no,’ fact or basic information seeking questions (Chin & Osborne, 2008) | explain a phenomena (e.g., decomposition)  
- Writing questions that do not have ‘yes’ or ‘no’ or one word answers  
- Writing relationship questions rather than definition questions | “Let me ask this. What are not productive questions? There are some questions that are less productive than others. What are some that are less productive? What types of questions? ... Questions with yes or no answers. "What.." type questions. Okay. Okay. Questions that lack specificity.” |
|---|---|---|---|
| Setting up and conducting an investigation | - Set up investigations to purposefully test a hypothesis or prediction, or answer a question  
- Set up investigation to isolate a variable or manipulate only one variable (Kanari & Millar, 2004; Lehrer & Schauble, 2015; NRC 2012) | - Planning trials to test a hypothesis or prediction  
- Planning and conducting investigation (experiment or second-hand investigation) to answer specific question  
- Purposefully planning and conducting investigations rather than trial-and-error or random choices  
- Isolating or controlling variables, or manipulating only one variable at a time  
- Carefully collecting, recording data | “I just want to point out that, remember: your prediction should be, kind of driving where you start at, or how you start. Just like with the last one, we didn’t want to just, kind of just, randomly start choosing numbers and levels and all that kind of stuff. So, that should drive. Your prediction, or your group’s predictions should drive, kind of where you’re starting with your trials.”  
“Now, when we’re doing this [simulation experiment] we need to make sure we’re only pulling on one strand at a time… You guys know about controls, and dependent, independent variables, you guys have learned about that in the past. When you are dealing with variables, how many do you want to deal with at a time?” |
| Analyzing data | - Analyze and interpret data by identifying variables of interest and looking for relevant patterns and relationships between them (Kuhn, Iordanou, Pease, & Wirkala, 2008; Hug & McNeill, 2008; Lehrer & Schauble, 2015; Sandoval & Reiser, 2004) | - Looking for patterns or relationships in their data in order to analyze and understand what is happening | “So what do you usually do with your data after you have received it? You get the numbers, you get all the things that you need, the next step is to... To analyze it. To think about what those numbers mean. You’re gonna find that on pages 38-39 and you’re gonna start analyzing the data and drawing some conclusions on your analysis.”  
“So by doing the simulations you guys have a crude view of, gain some data. So what do you with data after you get it?” |
| Using evidence | - Scientific explanations make claims about a phenomena (Berland & Reiser, 2009)  
- Claims should be justified with appropriate data/evidence (McNeill et al., 2006; Toulmin, 2009) | - Include evidence or data to support explanation  
- Need to justify or back up ideas  
- Explain why they think | “Ok but remember you have to have evidence, we can’t just say a claim without having evidence.”  
“When you are finished with all 5 trials, page 32 is going to ask you a couple questions with regards to what you
- Provide reasoning for how evidence supports the claim (McNeill et al., 2006; Toulmin, 1958)
- Explanations should persuade others
(Berland & Reiser, 2009; McNeill et al., 2006; Osborne, 2010; Sandoval & Reiser, 2004, Toulmin, 1958)

- Need to persuade or convince others

something, provide reasoning for their ideas in explanations

found through running those trials. You should be able to back those up with evidence from what you did. Ok? Make sure you’re doing that. You can discuss it as a group, and what you want to write down, but just make sure that you’re providing the evidence that is needed.”

“Here’s where we’re justifying with evidence. And, um, [student] said, ‘Hey, do we just write down: This is what we found, because the ratio is this’ Yes, that’s exactly what you’re writing.”


The code for *epistemic aims of science classroom activity* was based on the theoretical notion that an epistemic aim is a goal to create an epistemic product (Barzilai & Chinn, 2018) and a key epistemic aim of science is constructing scientific knowledge and understanding to explain the natural world. Based on a situated perspective of understanding the epistemology of science (Sandoval, 2005), this code focused on how teachers discussed goals of scientific knowledge construction of specific science activities in their classrooms. This code was used to identify teachers’ discourse aligned with helping students develop this metacognitive knowledge about the epistemic aims of a specific science activity including “understanding of why particular aims are important, what they entail, what it takes to achieve them” (Barzilai & Chinn, 2018, pg. 18).

This coding category for *epistemic ideals of science* was based on the notion that epistemic ideals are the criteria or standards for developing or evaluating epistemic products including what the criteria are, why, when, or how to apply them (Barzilai & Chinn, 2018). The sub-codes for this category were deductively based on prior literature, as described previously (see theoretical description in Table 3), and inductively refined from the data in order to capture the different types of ideals teachers discussed with their students. The four sub-codes for epistemic ideals of science distinguish criteria associated with the scientific processes of generating questions, setting up and conducting an investigation, analyzing data, and using evidence. These codes were used to identify teachers’ discourse aligned with helping students develop metacognitive knowledge about epistemic ideals in science, including “the meaning and significance of epistemic norms and criteria for evaluating what people know, including the reasons why norms and criteria are important and what it takes to meet them” (Barzilai & Chinn, 2018, pg. 18).
The first author and a second researcher independently coded 20% of the classroom video transcripts for all teachers. Cohen’s kappa was used to calculate inter-rater reliability for each of the five codes, and for each code we computed Shaffer’s rho (Shaffer, 2017) to test the generalizability of Cohens’ kappa (epistemic aims of specific science activity K=.81, ρ(0.65) < 0.01; epistemic ideals for generating questions K=.95, ρ(0.65) < 0.01; epistemic ideals for setting up and conducting an investigation K=.78, ρ(0.65) < 0.01; epistemic ideals for analyzing data K=.78, ρ(0.65) < 0.01; and epistemic ideals for using evidence K=.82, ρ(0.65) < 0.01). Thus for all codes our measure of inter-rater reliability was significantly over the threshold of K>0.65, indicating substantial agreement (Stemler, 2001). Discrepancies were resolved via discussion, and the first author coded the rest of the data.

**Connections between epistemic aims and ideals.** We used Epistemic Network Analysis (ENA) to further investigate how teachers made connections between epistemic aims and ideals of science in their discussions with students (Shaffer, 2017; Shaffer et al., 2016). ENA builds networks to model interactions between ideas present in discourse. This method that can be used to identify, quantify, and model the connections between ideas in coded discourse data (Shaffer et al., 2016). A fundamental assumption of ENA is that “the structure of connections among cognitive elements is more important than the mere presence or absence of those elements in isolation” (Shaffer et al., 2016, p. 10). Given the connected nature of practice (Shaffer, 2017) and of epistemic aims and ideals (Chinn et al., 2016), it may be particularly important for a teacher to discuss these aspects of science in relation to each other in order to help students understand how the various activities they do a science class and the criteria for successfully participating in those activities are connected and contribute to the larger aim of developing explanations and understanding. ENA was thus an optimal method to investigate how teachers provided
instruction for science as epistemic practice and to capture a more complete picture of teachers’ instruction beyond counting the frequencies of talk about aims and ideals.

Our units of analysis were all of the line of teachers’ talk, subsetted by teacher. ENA uses an algorithm that constructs network models for each line of data, using a moving window that captures the co-occurrences of codes within a defined number of lines in the conversation, termed the recent temporal context (Siebert-Evenstone et al., 2017). We defined this window as 10 lines, including each line and the previous 9 lines, to account for connections teachers made within approximately one or two minutes of discussion. These networks for each line of data are then aggregated into mean networks for all the lines of data that corresponded to each unit of analysis (i.e., each teacher’s talk). This resulted into one mean network for each teacher.

We created our model based on the five epistemic aims and ideals codes described in Table 3 (epistemic aims of science classroom activity; and epistemic ideals of: generating questions, setting up and conducting an investigation, analyzing data, and using evidence) to show how each teachers made connections between these aspects of scientific practice during the compost unit. The nodes of the network are these five codes, and the edges are weighted to represent the number of connections a teacher made between two codes, with thicker edges representing more frequent and stronger connections. We defined conversations as all of the lines of data in one class period, subsetted by teacher.

The ENA algorithm optimizes the placement of the nodes in the network space to highlight the differences between groups, allowing for comparisons among the five teachers in the space (see Shaffer et al., 2016 for more information on the algorithm underlying ENA).

We projected the networks of teachers’ instruction in the same space as the networks of students’ understanding about the epistemic practice of science (described later) so that the nodes
in all of the networks presented in this study would be located in the same place. This allowed us to more easily compare the connections between epistemic ideals that teachers made in their instruction and that students made in their understanding – four epistemic ideals codes (asking questions, conducting investigations, analyzing data, and using evidence) overlapped between the teacher (Table 3) and the students (Table 4) coding schemes. However, two codes did not overlap between these schemes (epistemic aims, Table 3; share ideas with other scientists, Table 4). In order to project networks of teachers’ instruction and students’ understanding in the same space, we needed to include all of these codes in the model. When only looking at the networks for teachers’ instruction, this resulted in one “unused” node in networks (share ideas with other scientists). When only looking at the networks for students’ understanding, this again resulted in one “unused” node in the networks (epistemic aims). In the figures of networks we present in the results, we have erased these “unused” nodes for ease of interpreting the networks.

Discussion of epistemic aims and ideals over duration of unit. We were also interested in understanding how teachers talked about epistemic aims and ideals over time with respect to frequency and sequence. This could be especially important for understanding how teachers are helping students see relationships between these aspects of science. For instance, did teachers discuss aims with their students consistently over the multi-week unit or mostly at the beginning of a unit? Did they discuss epistemic ideals associated with various scientific processes in isolated instances or do they weave these ideas into each class period to help students see how they are related to each other?

To understand how the teachers talked about epistemic aims and ideals with their students over time, we used chronological representations of teachers’ discourse as described by Luckin and colleagues (2001) and Hmelo-Silver (2003). The Chronologically Ordered Dialogue
and Features Used (CORDFU; Luckin et al., 2001) and Chronologically-ordered Representation for Tool-Related Activity (CORDTRA; Hmelo-Silver, 2003) methodologies use similar processes to create a graphical chronology of discourse. These representations allowed us to investigate differences in when teachers talked about epistemic aims and ideals with their students over time. For example, this allowed us to see whether teachers only talked about the aims of specific science activities at the beginning of the experiments, or if there was sustained and continual discussion of the purpose of activities throughout.

**Students’ apt epistemic performance.**

**Students’ understanding of the epistemic practice of science.** We assessed students’ understanding of the epistemic nature of scientific practice by analyzing their post-unit responses to a question about how scientists construct and defend explanations. We coded each student’s response for the presence of various processes or criteria associated with the processes that the scientific community might use to construct and defend explanations. Codes were developed to mirror the epistemic ideal codes for *asking questions, setting up and conducting an investigation, analyzing data*, and *using evidence* used in the classroom video analyses. Codes were motivated by prior research and refined based on our data, as shown by the theoretical descriptions and applied descriptions, respectively, in Table 4. In this refinement, we added one additional code, *share ideas with other scientists*, to reflect an important idea about the collective practice of the scientific community (i.e., Cavagnetto, 2010; Osborne, 2010) that appeared in students’ responses. This resulted in five codes: *ask questions, set up and conduct investigations, analyze data, use evidence, and share ideas with other scientists* (see Table 4 for descriptions and examples).
The first author and a second researcher independently coded 20% of the student responses. Cohen’s kappa was calculated for each code, and for each code we computed Shaffer’s rho (Shaffer, 2017) to test the generalizability of Cohens’ kappa (ask questions K=.92, \( \rho(0.65) = 0.01 \); set up and conduct investigations K=.80, \( \rho(0.65) < 0.01 \); analyze data K=.90, \( \rho(0.65) = 0.03 \); use evidence K=.74, \( \rho(0.65) < 0.01 \), and share ideas with other scientists K=1, \( \rho(0.65) = 0.01 \)). Thus for all codes, our measure of inter-rater reliability was significantly over the threshold of K>0.65, indicating substantial agreement (Stemler, 2001). All discrepancies were resolved via discussion, and the first author coded the rest of the data.

We used ENA (Shaffer, 2017; Shaffer et al., 2016) to analyze the students’ understanding of how different aspects of the epistemic practice of science are connected and play a role in the scientific community’s pursuits to construct explanations. We would expect students who have a better understanding of the epistemic practice of science to mention more ideas about scientists conducting investigations (experiments and/or research), collecting and analyzing data from their investigations, and then using or presenting their evidence from their investigations to convince others of their explanations. ENA allowed us to investigate the connections students made between these aspects of scientific practice.

Our units of analysis were all students’ responses, subsetted by teacher. ENA uses an algorithm that constructs network models for each line of data, using a moving window that captures the co-occurrences of codes within a defined number of lines in the conversation, termed the recent temporal context (Siebert-Evenstone et al., 2017). Because we wanted to project the networks of students’ understanding in the same space as the networks of teachers’ instruction (described above), we needed to keep the window at 10 lines. To ensure that the networks of students’ understanding only reflected connections made within a single students’
response, we defined conversations as each student’s one line of data, subsetted by teacher. In
doing this, networks only took into account co-occurrences of codes within an individual
student’s response. These networks for each line of data are then aggregated for all the lines of
data, for each unit of analysis (i.e., students’ responses by teacher). This resulted into one mean
network of students’ understanding for each teacher.

We created our model based on the five codes described in Table 4 (ask questions, set up
and conduct investigations, analyze data, use evidence, and share ideas with other scientists) to
show how each student made connections between aspects of scientific practice. The nodes of
the network are these five codes, and the edges are weighted to represent the number of students
that made this connection in each teacher’s class, with thicker edges representing more frequent
connections.

The ENA algorithm optimizes the placement of the nodes in the network space to
highlight the differences between groups, allowing for comparisons among the students from the
five teacher’s classes in the space (see Shaffer et al., 2016 for more information on the algorithm
underlying ENA).

As described above, the networks for students’ understanding were projected into the
same space as the networks for teachers’ instruction. In order to do this, we needed to include
two codes that did not overlap between these schemes (epistemic aims, Table 3; share ideas with
other scientists, Table 4) in the model. When only looking at the networks for students’
understanding, this resulted in one “unused” node in the networks (epistemic aims). In the
figures of networks we present in the results, we have erased these “unused” nodes for ease of
interpreting the networks.
### Table 4

**Coding Scheme for Students’ Understanding of the Epistemic Practice of Science**

<table>
<thead>
<tr>
<th>Code</th>
<th>Theoretical Description / Basis for Code</th>
<th>Applied Description in Context (Scientists try to convince others about their explanations by:_____)</th>
<th>Examples</th>
</tr>
</thead>
</table>
| **Ask questions** | - Questions should be researchable or testable in order to conduct an investigation (Chin & Osborne, 2008; Lehrer & Schauble, 2015)                                                                                                 | - Asking questions that guide their research and experiments  
- Writing questions that are researchable or testable  
- Writing questions that will help gather information needed to explain a phenomena (e.g., decomposition)  
- Testing an idea they have  
- Creating hypotheses                                                                 | “First they ask questions, research, and conduct experiments to find answers”  
“When scientists have a theory, or an idea, they do many experiments.”                                                                                       |
| **Set up and conduct investigations** | - Questions focused on explanations, cause-and-effect, or relationships (how or why) are considered higher-level questions than ‘yes or no,’ fact or basic information seeking questions (Chin & Osborne, 2008) | - Planning and conducting investigation (experiment or second-hand investigation) to answer a question  
- Testing a hypothesis or prediction  
- Conducting experiments (fair experiments)  
- Conducting research  
- Purposefully planning and conducting investigations rather than trial-and-error or random choices  
- Isolating or controlling variables, or manipulating only one variable at a time  
- Carefully collecting or recording data  
- Conducting multiple trials                                                                 | “Scientists run many tests and narrow it down to one possible answer”  
“Scientists also use experiments”  
“They would perform an experiment and record data to what they see and what’s happening”                                                                                              |
| **Analyze data** | - Set up investigations to purposefully test a hypothesis or prediction, or answer a question  
- Set up investigation to isolate a variable or manipulate only one variable (Kanari & Millar, 2004; Lehrer & Schauble, 2015; NRC 2012)  | - Looking for patterns or relationships in their data (e.g., cause and effect)  
- Analyzing data to understand what is happening  
- Making sense of data (e.g., graphing, calculating)                                                                 | “Once they get enough data to support there argument they will do a final analyzes”  
“When when scientists find a pattern in their data then they are able to backup their claims with facts and evidence”                                                                                                  |
| Use evidence                                                                 | - Scientific explanations can make causal claims about a phenomena (Berland & Reiser, 2009)  
|                                                                             | - Claims should be justified with appropriate data/evidence (McNeill et al., 2006; Toulmin, 1958)  
|                                                                             | - Provide reasoning for how evidence supports the claim (McNeill et al., 2006; Toulmin, 1958)  
|                                                                             | - Explanations/arguments should persuade others  
|                                                                             | (Berland & Reiser, 2009; McNeill et al., 2006; Osborne, 2010; Sandoval & Reiser, 2004, Toulmin, 1958)  | “If the subject reacts differently every time then they keeps doing the test and notice a pattern with their data to conclude that this happens when you do this to this and so on.”
|                                                                             | - Including evidence or data to support explanation  
|                                                                             | - Justifying or back up ideas  
|                                                                             | - Explaining why they think something, providing reasoning for their ideas in explanations  
|                                                                             | - Using/showing other people their “facts,” “numbers,” “results”  |
| Share ideas with other scientists                                           | “They convince us by showing the data and research”  
|                                                                             | “To convince people of conclusions they need proof”  
|                                                                             | “…using evidence to explain their reasoning”  |
|                                                                             | - Critique and feedback from others are core to constructing knowledge in science  
|                                                                             | - Scientific ideas undergo critical examination by the community before they are accepted; this can occur through conferences, symposia, and peer review  
|                                                                             | - Collaborate to build scientific knowledge (Cavagnetto, 2010; Osborne, 2010)  |
|                                                                             | - Sharing or comparing findings and ideas with other scientists  
|                                                                             | - Getting feedback from other scientists (peer review)  
|                                                                             | - Collaborating with other scientists  |
|                                                                             | “They show there work to other scientist to proof and read there work”  
|                                                                             | “They also do conferences to explain what they have discovered” }
Students’ participation in the epistemic practice of science. To investigate students’ participation in the epistemic practice of science, we analyzed students’ journals for aspects of their ability to apply epistemic ideals to conduct an experiment, analyze and interpret their data, and use evidence to support their claim.

For conducting an experiment, we specifically looked at how students thought about trials building upon each other, in the context of investigating how moisture affects decomposition in compost. After each trial of their experiment, students’ data charts prompted them to think about the success of the most recent trial and explain how they could change the moisture content in the next trial to improve the rate of decomposition. We analyzed the written suggestion and rationale students provided between trials for the next steps they would take in their experiment, and students received a score of 0-2 based on the completeness of their rationale and their follow-through on the subsequent trial (see Table 5).

To analyze students’ ability to analyze and interpret data from their experiment, we looked at students’ written responses about the findings from their experiment, specifically the relationship between moisture content and the rate of decomposition in compost. Students received a score of 0-2 based on their ability to state findings that aligned with the data they collected in their experiment.

Finally, we analyzed students’ ability to use evidence from the experiment to support the claims they made. In their journals, students were asked to provide their evidence and were instructed to look back at their data chart and use that information to support their idea. Students received a score of 0-2 based on their ability to use specific and appropriate data from their experiment to support their claim. To receive a two, students could have used specific numbers
and values from their trials or provided a thorough qualitative description about what happened in their experiment as evidence.

The first author and a second researcher independently scored 20% of the student journals. Cohen’s kappa was calculated for each of the three aspects of practice (conduct investigation K=.73; analyze and interpret data K=.74; use evidence K=.74). In order to see if there were any differences in students’ ability to participate in these three different aspects of scientific practice, we conducted three one-way analysis of variance (ANOVA) $F$ tests with teacher as the between groups factor to compare students’ mean scores (0-2) on conducting investigation, analyzing and interpreting data, and using evidence. Tukey post-hoc pairwise comparisons were used to identify significant differences between specific teachers, controlling for Type I error. We chose this analysis to explore any possible differences between teachers to better understand how teachers’ instruction might have supported students’ participation in science as epistemic practice.
### Table 5
**Coding scheme for analyzing students’ participation in the epistemic practice of science**

<table>
<thead>
<tr>
<th>Student Journal Source: Conduct investigation: Thinking about trials as building upon each other</th>
<th>Code</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
</table>
| Experiment data tables: “How could you change the amount of moisture to get a better result? Explain” | 0 | - Does not fill out data chart (blank)  
- Does not provide suggestion or rationale for next trial | - blank, or blank for most trials  
- “too wet” not a suggestion |
| 1 | - Provides suggestion for next trial and partial rationale based on previous trial  
- Or provides suggestion, rationale for next trial but does not follow through | - “lower moisture” then increased moisture  
- “less water”  
- “more moisture” |
| 2 | - Clearly provides suggestion and explains rationale for next trial based on previous trial  
- Makes changes in the next trial that follows from previous trials / rationale | - “Trial 1 was not successful because we had too much water for the bacteria to function at an efficient rate. Decrease the amount of moisture”  
- “Unsuccessful. Too much water. No oxygen flow. So, less moisture.” |

<table>
<thead>
<tr>
<th>Student Journal Source: Analyze and Interpret data</th>
<th>Code</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
</table>
| Report out: “We found that ___” and “We think the ideal is ___” | 0 | - Does not answer prompt (blank)  
- Statement contradicts their data  
- Not able to state ideal % moisture | - blank  
- “you need a particular amount of moisture in your compost for it to work” |
| 1 | - States finding  
- States finding that aligns with data from their experiment  
- Partial interpretation of data, only accounts for some trials | - “The moisture percentage needs to be around 40-50%”  
- “We have to have around 45 to 50% of moisture in order to have fast decomposition.” |
| 2 | - States accurate finding about relationship between moisture and decomposition  
- Accounts for all trials to fully interpret relationship (i.e. what happens if moisture is too high and/or too low based on their trials) | - “Moisture affects the organic material because with little moisture the bacteria cannot function, slowing the rate of decomposition. Same goes for too much moisture.”  
- “Too little moisture will slow the rate of decomposition and also will too much. Great compost is balanced.” |

<table>
<thead>
<tr>
<th>Student Journal Source: Use evidence to support claim</th>
<th>Code</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
</table>
| Report out: “We know this because (refer back to your data chart) ___” | 0 | - Does not answer prompt (blank)  
- Does not include evidence or reference their experiment/data chart  
- Inappropriately provides evidence that contradicts their claims | - blank |
| 1 | - Incomplete or partial use of evidence  
- References experiment but does not use data or description as evidence  
- Does not provide specific information about how they know their claim is true | - “Our trials worked”  
- “We did some more research/experiments to find this” |
| 2 | - Uses specific data from experiment (numbers or qualitative data) to support claim. Points to the data from experiment or clearly describes what happened in experiment  
- Evidence is appropriate, supports the claim made | - “If the levels were over 60 or under 40, the composting process will be slow”  
- “When the moisture was less than 40% in Trial 5, it was a slow decomposition. Also when it was more than 60% moisture in Trial 4 the decomposition was slow.” |
Results

We were interested in understanding how five teachers provided instruction about epistemic aims and ideals in their classrooms, and how this instruction related to students’ understanding of and participation in the epistemic practice of science. The results are organized as follows: Comparisons between teachers’ instruction with respect to (a) teachers’ connections between epistemic aims and ideals; (b) teachers’ discussions of epistemic aims and ideals over the duration of the unit. Comparisons between students’ apt epistemic performance with respect to (c) students’ understanding of the epistemic practice of science; (d) students’ participation in the epistemic practice of science.

Teachers’ Connections Between Epistemic Aims and Ideals

We examined how the five teachers made connections between epistemic aims and epistemic ideals of science in their discussions with students by looking at the relationships between codes in the transcripts of teachers’ instruction. We were particularly interested in how teachers connected the various criteria (ideals) employed in science to achieve the overarching goals of developing explanations (aims) in science. We were particularly interested in how teachers connected the ideal of using evidence to aims and other ideals, because the successful use of evidence is central to the scientific community’s use of argumentation and the advancement of scientific knowledge (Berland & Reiser, 2009; McNeill et al., 2006). We used the mean network plots for each teacher from Epistemic Network Analysis (ENA) and qualitative examples to understand the differences in how teachers made connections in their instruction. Together, the ENA results and qualitative examples provided comprehensive pictures of how teachers made connections over all of the class periods and rich descriptions of how teachers talked about aims and ideals in relation to each other, respectively.
We found differences in the overall strength and frequency of connections and in the particular connections each teacher made in their discussions with students. Looking across the teachers, we found that Mr. C, Mrs. S, and Mr. P all made stronger connections between epistemic aims and ideals than Mrs. J and Mrs. M, as shown by the thickness of the lines in the mean network plots in Figure 1. The mean network plots for each teacher show the frequency with which teachers made connections between epistemic aims and ideals, designated by the weight of the lines between nodes in each plot. The thicker lines in the mean networks for Mr. C, Mrs. S, and Mr. P indicate that these teachers frequently connected ideas about epistemic aims and various epistemic ideals in their instruction. In contrast, Mrs. J and Mrs. M did not talk as much about epistemic aims and ideals in relation to each other (shown by the generally thinner lines in Mrs. J and Mrs. M’s networks). Figure 1 shows that:

- Mr. C made strong connections between epistemic aims of science activities, epistemic ideals for conducting investigations, and epistemic ideals for using evidence.
- Mrs. S made strong connections between epistemic aims of science activities, epistemic ideals for conducting investigations, epistemic ideals for using evidence, and epistemic ideals of asking questions.
- Mr. P made strong connections between epistemic aims of science activities, epistemic ideals for conducting investigations, and epistemic ideals for analyzing data.
- Mrs. J made connections between the epistemic aims of science activities, epistemic ideals for conducting investigations, but her connections between other aspects of scientific practice were weaker and less frequent than other teachers.
- Mrs. M made the fewest connections in her instruction.
Figure 1. Mean networks for each teacher showing connections made between epistemic aims and ideals in teachers’ talk.

Examples of teachers’ instruction. In the following excerpts from classroom discourse, we highlight the strong connections that Mr. C, Mrs. P, and Mr. P made in their instruction.
**Example from Mr. C’s class.** In Mr. C’s discussions with students, he often emphasized the importance of thoughtfully conducting trials in students’ experiments and using evidence to support claims. He talked a lot about how to use evidence in connection to conducting investigations and the epistemic aims of activities. These strong connections that he made throughout the compost unit are shown clearly in Figure 1. In the following example, we can see how Mr. C introduced the second simulation experiment students conducted about how moisture content affects decomposition by discussing epistemic ideals about conducting investigations and prompting students to remember the goal of the activity:

1. Mr. C: So today you should be running through your trials with regards to moisture. If you look at page 35, it’s going to give you a breakdown of moisture [referring to chart that contains information about moisture content in various organic materials]. This moisture content is with the assumption that we have the ideal carbon to nitrogen ratio. So keep in mind, that all factors being the same, that’s what moisture content should be. So green is about 75%, and the rest about 0%. So you’re going to want to use that chart as you work through your moisture simulations.
2. [brief pause]
3. And think about your trials, how you set up each trial with moisture goals. So it shouldn’t be something as you go through the trial, it shouldn’t be willy-nilly that you’re just throwing numbers out there or adding amounts of water and not, reducing amount of water so on and so forth…Think about your goals, what variable will be important to change and what are you going to control.

Mr. C first provided some general information (lines 1-7) about how students would be using the virtual compost simulation to conduct trials about the variable of moisture content. Students had previous conducted an experiment to identify the ideal carbon to nitrogen ratio of materials for composting (referenced in line 4) and would now be combining organic materials that differed in moisture percentage, by weight (line 6). Instead of stopping after giving students the information they needed to conduct the experiment, Mr. C continued (lines 9-13) to talk about an important criteria for conducting investigations in science: thoughtfully and purposefully conducting trials
rather than “willy-nilly” testing random values (line 10) and “just throwing number out there” (line 11). He also connected this idea of thoughtfully conducting trials to the purpose or aim of the experiment by prompting students to “set up each trial with moisture goals” (line 9) and to, “Think about your goals” (line 13). Mr. C provided a reason for why students needed to be thoughtful and purposeful in their trials: so they could reach their goal of understanding how much moisture content would be ideal for creating their compost.

Mr. C almost began explaining what students would do after they finished running their trials, but stopped again to reemphasize the importance of students thinking about their trials as they were conducting the experiment:

14 Mr. C: So you’re gonna run through those trials and when you’re done with those trials,
15 just like before there are 5.
16 [brief pause]
17 As you do the trials here’s the one thing that I had to explain to many groups. Don’t just
18 focus on that data collection, these questions are there to get you thinking about what
19 you want to do next or what you can change. What variable you want to manipulate or
20 change as you move forward.

We can see that Mr. C was about to transition in line 14 and 15, but then he returned to the epistemic ideal of purposeful experimentation. Rather than focusing on the more procedural aspects of “data collection” (line 18), he wanted students to take time to think about the question prompts embedded in their data tables that asked them to think about “what you want to do next or what you want can change” (lines 18-19). This excerpt of how Mr. C introduced an experiment exemplifies how he went beyond just giving students an opportunity to do an investigation. He discussed important criteria for how to successfully participate in this investigation and how these criteria related to helping students reach their goal of explaining how moisture affects decomposition, making the connections captured in Figure 1. Mr. C continued
by discussing how students would use evidence from these trials to support their findings when they had finished conducting the trials.

21 Mr. C: So you’ve got 5 of those, and then you’re back to your “Report Out” page. “Report Out” page kinda looks the same. What evidence do you have to support your findings?
22 The “Report Out” page is, as I said the other day, those are the ones I’m using as assessments. So I’m not just assessing what you find, I mean each group will find something different. Assuming that they’re setting up their trials differently. But what I’m really assessing, what I’m really looking for is you supporting your findings. And not just saying well we know this because we ran the simulator…Okay so make sure when you are explaining your evidence…so keep in mind question 2, what is the ideal % moisture? Okay, refer back to your data.

Mr. C directed students to the next page of their student notebooks, the “Report Out” page (line 21), where they would report their findings and draw their conclusions from the experiment, reminding them that this page “looks the same” as after their previous experiment (line 22). He highlighted a central epistemic ideal of science of using evidence to support claims when he asked, “what evidence do you have to support your findings?” (line 22). He emphasized the importance of being able to use evidence to support claims by reminding students that he would be using these as assessments (line 23-24). He told students that he was “not just assessing what you find” (line 24), but even more interested in how they were “supporting your finding” (line 26). Telling students that something will be graded is often an indication to the them that something is important or valued by the teacher, so here we can see how Mr. C helped students recognize that using evidence is a key criteria for successfully participating in science. To help students better understand ideals for how to use evidence, Mr. C described that “just saying, well we know this because we ran the simulator” and conducted trials did not count as sufficient evidence (line 27). In order to successfully use and explain their evidence (line 28), students needed to refer back to their actual data from the experiment (line 29).
Through this example, we can see how Mr. C made a point to talk about the use of evidence with his students as a standard of scientific practice and provided some guidance on how to successfully use evidence. He tied the importance of students purposefully conducting trials in their experiment to the goals of the experiment and to using evidence from these trials to support their claims, illustrating how these aspects of scientific practice were related. Mr. C’s strong connections between epistemic aims, ideals for conducting investigations, and ideals for using evidence were reflected in his network in Figure 1 and signified that he emphasized these ideas together often. Across all of the teachers, Mr. C’s instruction stood out for his focus on epistemic aims, conducting investigations, and using evidence.

**Example from Mrs. S’s class.** Similar to Mr. C, Mrs. S made frequent connections between the use of evidence and conducting investigations. She also seemed to talk more than the other teachers about the purpose of what they were doing in class. Mrs. S frequently discussed the aims or goals of activities with her students, discussed criteria for conducting investigations, and emphasized that students needed to have reasons for their thinking and evidence to prove their claims. These trends in her teaching were reflected in the strength of the connections she made epistemic aims and ideals for conducting investigations, using evidence, and asking questions (Figure 1). The following example illustrates how Mrs. S often helped students remember and understand the epistemic aims, or goals for constructing knowledge, of a particular activity they were doing. Here, students were using computers to conduct a research investigation to learn information about factors that influence decomposition to help them solve their challenge of designing an effective compost. When Mrs. S saw that a student, Jen, was randomly clicking around on the computer, she drew Jen’s attention back to the purpose of the activity to help Jen and the used the opportunity to remind the whole class about the purpose:
Mrs. S: So instead of just clicking, did you read about how water actually affects the compost?

Jen: I was kinda just playing with the scroll out here.

Mrs. S: Okay, but hold on, that's great and all, but, is that going to help you answer your question?

Jen: (inaudible).

Mrs. S: Okay, and is it going to help you with your compost challenge?

Jen: No.

Mrs. S: Probably not. But reading this, you're looking for answers that are gonna help you with your compost.

Mrs. S: (to whole class) Remember, your overall goal is to find answers to your questions so it can help you with your compost and with our challenge, that's one of the purposes of our research.

When Jen appeared directionless, Mrs. S reminded Jen of the goal of the activity by asking if what Jen was doing would help her answer the question she was researching (line 3). Mrs. S further connected the current research activity to the larger goal of solving the “compost challenge” (line 6), reminding Jen about the overarching purpose of what she was doing (line 8). She made a point to remind the whole class of the “overall goal” of their research “to find answers to your questions so it can help you with your compost and with your challenge” (line 10-11). As Mrs. S continued the conversation, Jen was not sure what to do next in her research. Mrs. S responded by emphasizing epistemic ideals that investigations are driven by questions and the importance of providing evidence to answer those questions.

Jen: But which one should we do?

Mrs. S: Well, it's all gonna depend on what questions. So, this question says “what factors help decomposition occur faster?” Okay, well that's kind of - that was kind of this question. Break down matter, help decomposers. So what does help a decomposer?

Jen: (inaudible).

Mrs. S: But I'm saying maybe you should create a couple different questions, we can add questions, we can add new questions, on here? How does -
Jen: We already answered that question.

Mrs. S: Huh?

Jen: We already answered that question.

Mrs. S: For sure? Like 100%? If you think so, then I would love for you to prove it on here. Show me evidence from this that proves that you know what that means and how it affects it. Does that make sense? So if you say "yes, we know what sunlight does," great, show me your proof. Exactly what does it do, and how is it beneficial? So then maybe what's a keyword I could start with then?

Jen: Sunlight?

Mrs. S: Sunlight. Does that make sense? So if you think you know how it goes, prove it.

When Jen asked what she should do next (line 13) Mrs. S brought up important ideals in science to guide Jen’s thinking, that research investigations are driven by and “depend on what questions” someone has (line 14) and that questions should be written in such a way that they are researchable (line 17). Mrs. S tried to help Jen and her group rephrase some of their statements into write researchable “how” questions (line 17). When Jen mentioned that her group “already answered” a question that Mrs. S identified (line 21 and 23), Mrs. S reminded the students of the importance of proving their ideas with evidence from their research (lines 24-27). Mrs. S made it clear that she wanted students to go beyond simply stating what they found when she said, “So if you say ‘yes, we know what sunlight does,’ great, show me your proof” (lines 26-27). As the students needed to go back and find some additional evidence to support their idea that sunlight was beneficial for compost, Mrs. S prompted Jen and her group to continue researching (line 28) with a focus on sunlight (line 30).

This episode exemplifies how Mrs. S continually reminded students about the purpose of activities and talked with them about criteria for asking questions and using evidence in relation to conducting investigations. Mrs. S helped Jen, and the rest of the class, recognize that how she chose to conduct her research should be driven by her research questions and by the overarching
goals to build understanding about decomposition that would help her solve the composting challenge. These types of discussions in which she emphasized the purpose or goals of activities as she helped students understand how to successfully conduct investigations and generate questions were reflected in the strong connections from aims to conducting investigations and generating questions in her network (Figure 1). In this example, we also saw how Mrs. S emphasized the need to use evidence to support findings from an investigation. As seen in Figure 1, Mrs. S was one of the only teachers, along with Mr. C, who made strong connections to criteria for using evidence in their discussions with students.

**Example from Mr. P’s class.** Of all of the five teachers, we found that Mr. P made the most frequent connections to analyzing data. The following excerpt from Mr. P’s classroom demonstrates how he talked with his students about analyzing data, and in particular, how he tried to help students see that analyzing data was an critical step towards being able to support their claims with evidence. Mr. P was having a discussion with the whole class about the changes their observed in their group composts. Mr. P asked students to provide evidence to back up their claims, and when students struggled to provide evidence, he used the opportunity to help them analyze their data.

```
1 Mr. P: What other observations have you made? Qualitative or quantitative. What kind of changes have happened Matt?
2 Matt: Before we put the food in our stuff wasn’t decomposing but when we started doing that it started decomposing faster.
3 Mr. P: What evidence do you have that that was true?
4 Matt: What evidence?
5 Mr. P: What tells you that’s the case? What tells you it’s decomposing now that you put the browns in there?
6 Matt: I mean, we just…we just know…
7 Mr. P: How do you just know?
```
Matt: I don’t know.

Mr. P: Where can you look to see if there is evidence out there happening?

Matt: Because the simulation.

Mr. P: So through simulations, what about your notebook? Are you taking data on your composter?

Matt: (Inaudible)

Mr. P: Have there been changes that occurred in there that show you that's the case? Maybe when we have our discussion about moisture in a little bit maybe that will help you get there. Maybe it will help you understand what’s going on in there. You guys will start understanding what’s happening.

Here we see that Matt made a claim that his group’s compost “started decomposing faster” after they added food (line 3-4). Mr. P highlighted the important of using evidence when he asked “what evidence” Matt had that his statement was true (line 5) and continued to press for evidence (line 7-8 and 10). As Matt struggled and it became clear that he was not sure what evidence he could use to support this claim (lines 6, 9 and 11), Mr. P directed him to look at the data he had collected in his notebook for evidence (line 12, 14-15). Mr. P continued in lines 17-20 to illustrate that looking for “changes that occurred” in the data was a way to find evidence to support a claim (line 17). Being able to analyze data and identify what had changed was an important step in students being able to provide evidence and ultimately in “understanding what’s happening” in their composts. After this prompting, another student, Lucy, offered evidence from her group’s data:

Lucy: Our compost, when we put the carbon in, changed the scent. Before it smelled like permanent marker but now it's got basically the smell like dog poo added in with it.

Mr. P: So there’s a significant change in the scent that you have in there… Good, that shows something is happening in there right? That’s evidence that something has changed. You changed the composition of it and that changed the odor. That’s good.

Lucy: We had a bunch of moisture and it smelled horrible. And then we put in that sawdust and now it doesn't really smell. It doesn't really smell like, it doesn't smell bad.
Mr. P acknowledged that the change in scent that Lucy noticed in her data was evidence of change in decomposition (line 23-25). This led Mr. P to extend the discussion and ask deeper questions directed at helping students understand the relationships between data from their physical composts and their virtual simulation experiments.

28 Mr. P: So based on what you guys have been doing on the moisture simulations, does that make sense? Does what you saw in the virtual simulations does that go along with what you found in your real composters? And why? Joey.

31 Joey: Like on the simulator we measured out how many browns we needed and it said everything was going to work great. Like it was fast, the temperature was ideal. Everything was good. Then we put it in and nothing happened.

34 Mr. P: Has it changed anything?

36 Mr. P: Did that change the odor?

38 Mr. P: Does that fit what you found in virtual based on how much liquid there is, how much moisture there is? I looked at all of your guy’s notebooks as I went by, there is a change that’s occurred from your first, your initial one to the one Friday from Monday to today. Something has changed, it’s fluctuating. And the pattern has been the same at every single table. I’m just curious that you guys haven’t noticed that. You have it with you, take a look and see what changes occurred. Take a look at your data and analyze is a little bit.

47 Joey: (Inaudible)

48 Mr. P: What’s happened with yours? Anything major change? On the 18th you had I’m guessing that’s, okay so you’re initial one on the 9th of April was 66 degrees. This is for group, are you with Group 2? Okay Group 2 had an initial temperature of 66 degrees in their composter. When they tested it Monday it was 85 degrees F. When they tested it today it said the temperature is 80 degrees. So have there been some changes? The temperature went up right? How? Why did it go up and then over the last couple days start going back down again? Why do you think that is?
As the class conversation continued, Mr. P had clearly noticed a pattern in students’ data that they were not seeing (line 39-42). They struggled to see how changes in their data were patterns indicative of decomposition. He began to ask more guiding questions to help students understand how to analyze their data by looking for patterns and modeled how to look at specific pieces of data (line 48-54). In addition to providing instruction about analyzing and interpreting data in this example, Mr. P related ideas about analyzing data to students being able to successfully use evidence to support their claims and to the goal of building understanding about what happened in their investigations. These discussions around analyzing data highlighted the role analyzing data in scientific practice and were represented in Mr. P’s network (Figure 1) by strong connections between analyzing data, conducting investigations, using evidence, and epistemic aims.

**Summary about teachers’ connections between epistemic aims and ideals.** The strength of the connections Mr. C, Mrs. S, and Mr. P made in their instruction, modeled in each of their networks, quantitatively reflected the qualitative features of the instruction that we noticed in their classrooms. While fewer than the other teachers, Mrs. J and Mrs. M did make connections between aims and ideals in their discussions with students. Mrs. J tended to make connections between the purpose of activities and ideals for conducting investigations, but her connections between other aspects of scientific practice were weaker and less frequent than Mr. C, Mrs. S, and Mr. P. Even though Mrs. M made the fewest connections between epistemic aims and ideals, we found that she did sometimes connect epistemic ideals for investigations, generating questions, and analyzing data back to the aims of the activities students were doing. Making strong connections between epistemic aims and the ideals of the four aspects of
scientific practice investigated here may be important for illustrating how these aspects all contribute to the epistemic practice of science.

**Teachers’ Discussion of Epistemic Aims and Ideals Over the Duration of the Unit**

We also examined how the five teachers discussed epistemic aims and ideals over time. We used chronological representations of teachers’ talk to better understand the consistency with which teachers talked about epistemic aims and ideals throughout the lessons and when during individual class periods teachers tended to bring up these aspects of science. Each horizontal line in the graphs in Figure 2 represents a single code (labeled on the right side) and each occurrence of teacher talk in that category is shown along that line, in chronological order. Differences in the horizontal axis scales between teachers are due to differences in the number of turns of talk within each classroom. Dotted vertical lines mark the beginning of a new class period, included for context.

These representations revealed differences in the consistency with which teachers discussed epistemic aims and ideals over the course of the compost unit. Overall, we found that Mr. C, Mrs. S, and Mr. P (the top three graphs in Figure 2) tended to talk about epistemic aims and ideals with students more regularly throughout the unit, whereas Mrs. J and Mrs. M (the bottom two graphs in Figure 2) tended to have less frequent and more compartmentalized and isolated discussions.
Figure 2. Chronological representation of teachers’ talk about epistemic aims and ideals over time.

This pattern was especially noticeable in the teachers’ talk about epistemic aims of specific activities in their science classes and their talk about epistemic ideals of conducting
investigations and using evidence. While all of the teachers discussed the epistemic aims of activities students were doing, Mr. C, Mrs. S, and Mr. P discussed these aims with students more consistently throughout the unit while Mrs. J and Mrs. M seemed to decrease these discussions over time. As shown by the red squares in Figure 2, we can see that Mr. C, Mrs. S, and Mr. P regularly discussed the purpose and goals of activities with students over the duration of the unit. On the other hand, Mrs. J and Mrs. M discussed the aims of activities frequently in the first few class periods, but these discussions became less consistent over time. Mrs. J’s graph in Figure 2 shows that she spent additional time towards the beginning of the compost unit helping students understand the purpose of what they were doing, but these discussions decreased over time. As the unit continued, she tended to talk with her students about the purpose or goal of their activities only briefly at the beginning of a new class or activity. We can also see that Mrs. M’s talk about epistemic aims was often at the beginning of class periods or new activities and lessened over time. In the second half of the class periods, she only discussed the epistemic aims of activities with students once or twice per class, sometimes not at all.

This trend was also evident in teachers’ discussions about epistemic ideals of planning and conducting investigations, shown by the purple X. All of the teachers talked most frequently about these criteria, and the graphs showed that Mrs. S and Mr. P, in particular, talked regularly about ideals of investigations throughout the compost unit. Mrs. J and Mrs. M on the other hand, seemed to focus on these ideals towards the beginning and decreased these discussions over time, as indicated by the purple X’s becoming more spread-out and infrequent in the second half of the classes. For teachers’ talk about the epistemic ideals of using evidence, we found that Mr. C, Mrs. S, and Mrs. M mentioned this criteria for using evidence the most, shown by the orange circles. But, looking at when this talk occurred, we found that Mr. C and Mrs. S discussed these criteria
in almost every class period. Mrs. M, however, discussed using evidence in only about half of
the class periods. Mrs. M tended to have more isolated discussions about using evidence, while
Mr. C and Mrs. S brought up these criteria with students more regularly.

The five teachers similarly discussed epistemic ideals of asking questions in the first
couple of lessons, as shown by the green triangles in Figure 2. The timing of these discussions
clearly aligned with initial activities of the curriculum that asked students to write research
questions about factors that could influence decomposition. We did not notice differences in how
teachers discussed criteria for writing research questions during these initial activities. However,
Mrs. S briefly brought up criteria related to questions in the middle of the unit when she
reminded students that the questions they were asking could drive future research investigations
and experiments.

Mrs. J and Mrs. M showed a similar pattern of talking more about epistemic aims and
ideals of science in the earlier lessons of the compost unit. They both had some in-depth
conversations with students about epistemic aims and ideals, and they made some connections
between aims and ideals, as shown previously in Figure 1. However, these conversations were
less frequent than those of the other three teachers.

**Students’ Understanding of the Epistemic Practice of Science**

We compared students’ understanding of how the scientific community constructs and
defends explanations. We looked specifically at differences between the five teachers in the
connections students made between different aspects of scientific practice in their responses. The
connections between two nodes in the network plots indicated how many students in a teacher’s
class discussed both of those ideas in their response. The mean network plots for students’ post-
unit responses, by teacher, are shown below in Figure 3.
Figure 3. Network representations of students’ understanding about epistemic practice of science.

As be clearly seen in Figure 3, we found that students in all classes most often made connections between conducting investigations and using evidence, indicated by the heavily weighted line connecting these two nodes. While this connection was the most frequent for all teachers, the line weights indicated that Mr. C’s students made this connection more often than other students, followed by Mrs. J’s, Mr. P’s, Mrs. S’s, and Mrs. M’s students.
We found differences among the five teachers in the connections their students made between asking questions, conducting investigations, analyzing data, using evidence, and sharing information with other scientists. Looking across the teachers, we found that Mr. C and Mrs. S’s students made connections between more of these aspects of scientific practice than the other teachers’ students. The students in Mr. C’s class made the most connections between asking questions, conducting investigations, analyzing data, using evidence and sharing information with other scientists. His students had an understanding of how all of these aspects of scientific practice play a role in constructing and convincing others of explanations. A example provided in Table 6 from one of Mr. C’s students illustrated these connections. It was clear that this student saw that asking questions, conducting research and experiments, collaborating with other scientists, and using evidence to support their findings were all related and contributed to the goal of developing explanations.

Mrs. S’s students also made connections between how the scientific community asked questions, conducted investigations, analyzed data, used evidence, and sharing information with other scientists. In the example provided in Table 6, we can see how one of her students used many of these ideas together and demonstrated an understanding of how the scientific community conducts experiments, analyzes data from those experiments, and uses that data to build arguments that they share with other scientists for feedback.

Mr. P’s, Mrs. J’s, and Mrs. M’s students made fewer connections between different aspects of scientific practice than Mr. C’s and Mrs. S’s. Mr. P’s students made connections between conducting investigations, using evidence, and sharing information with others, but did not talk about analyzing data in relation to these other aspects of practice. Similarly to Mr. C and Mrs. S, Mr. P had some students who recognized the role that sharing information with others
played in scientific practice and knowledge construction. For instance, one student from Mr. P’s class mentioned that scientists conduct research investigations and then present their findings to others at conferences (see Table 6). Conferences are places where many scientists come together to share their findings and receive feedback from others, so including this idea may reflect an understanding of the communal nature of developing explanations in science.

Mrs. J’s and Mrs. M’s students made some connections between conducting investigations and asking questions or using evidence. The example from Mrs. J’s class in Table 6 shows how students might describe the connection between conducting an investigation to answer a question or to test a theory or an idea. The example from Mrs. M’s class shows how students would sometimes talk about conducting investigations and using evidence, but while conducting investigations and using evidence was the most common connection that Mrs. M’s students made, her students did not make this connection as often as the other teachers’ students.

Table 6

Examples of students’ responses showing their understanding about epistemic practice of science

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Example student response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. C</td>
<td>Scientists convince other people about their explanations for why things happen the way they do in the world around us with many steps. First they ask questions, research, and conduct experiments to find answers. They use other scientists discoveries and their own discoveries to draw conclusions and debate credibility and facts. They log, test, and take notes on information that they discover. Scientists collaborate with others to explain why things are and how things work. Finally, they use evidence and facts to support and display their findings to others in creative ways so many can learn about their findings about the way things happen around them.</td>
</tr>
<tr>
<td>Mrs. S</td>
<td>Scientist use data from their experiment to show people the truth behind of what they found. Lets say a scientist found out that tables are radioactive- but they are not!!!-they would perform an experiment and record data to what they see and what's happening. And lets say when they pour water on it it starts bubbling up and smoking. They would write that down in their journal/notebook. They would perform multiple experiments, and each one writing down- if you don't write it down you won't know what you did or how it worked, so if you found a cure to cancer but did not write down how</td>
</tr>
</tbody>
</table>
you did it you would no be able to make it again. Once they get enough data to support their argument they will do a final analyzes and show their work to other scientist to prof and read there work- This takes years not counting how long it takes to find a discovery. Once these process's are done they might wait a little bit, will eventually show there work to the public. Not everyone will agree with your finding though. There is nothing you can do about that, but what you can do is show all your work and data. And make everyone you can believe what you found—even if it sound's stupid.

Mr. P They write reports about their findings, and they conduct research. They also do conferences to explain what they have discovered.

Mrs. J When scientists have a theory, or an idea, they do many experiments. They do the different experiments over and over for long periods of time to make sure they are right.

Mrs. M Scientists give evidence and proof of what they find in their experiments and then if someone is doubting them, they show evidence of the way they conducted their research and how they came up with the conclusion that they did.

Together, the networks for each teacher’s students (Figure 3) and the example responses (Table 6) presented above capture differences in the depth of students’ understanding about the epistemic practice of science. Students in Mr. C’s, Mrs. S’s, and somewhat in Mr. P’s classes appeared to have a stronger and more connected understanding of how the scientific community constructs knowledge and explanations.

Relationship between teachers’ instruction and students’ understanding. Looking at the networks of teachers’ instruction and the networks of students’ understanding together, we noticed an interesting relationship between the connections teachers made between epistemic aims and ideals in their instruction and the connected nature of students’ understanding about how explanations are constructed in science. It appeared that teachers who made stronger connections between epistemic aims and ideals in their instruction (such as Mr. C and Mrs. S as presented earlier in Figure 1) had students who seemed to have a stronger understanding of how key processes of scientific practice were connected and contributed to the construction of scientific knowledge and explanations (as shown in Figure 3). We present contrasting cases of
Mr. C and Mrs. M here to illustrate this relationship. Figure 4 below shows the connections Mr. C and Mrs. M made in their instruction (from Figure 1) next to the connections their students’ made in their written responses (from Figure 3). This comparison highlights the alignment between the strong connections that Mr. C made between the epistemic goals of activities and criteria for successfully conducting investigations and using evidence, and the connections Mr. C’s students made between asking questions, conducting investigations, analyzing data, using evidence, and sharing findings with other scientists in order to construct convincing explanations. This comparison also highlights the alignment between Mrs. M’s less frequent connections in her instruction and her students’ more limited understanding of how aspects of science all contribute to the epistemic pursuits of explaining the natural world.

Figure 4. Alignment between the connections teachers made in their instruction and connections students made in their descriptions of the epistemic practice of science.
**Students’ Participation in the Epistemic Practice of Science**

We analyzed students’ journals to further understand their participation in the epistemic practice of science, with respect to 1) conducting investigations, 2) analyzing and interpreting data, and 3) using evidence, as described by coding scheme in Table 5. We conducted three one-way ANOVA *F* tests, with teacher as the between groups factor, to compare students’ scores (0-2) between teachers for the three aspects of scientific practice mentioned above. We wanted to understand whether students’ ability varied across the five teachers. Our analyses showed significant differences in students’ performance between the five teachers on all three measures: conducting investigations (*F*(4,105) = 4.830, *p* = .001); analyzing and interpreting data (*F*(4,105) = 10.323, *p* < .001); and using evidence (*F*(4,105) = 4.324, *p* < .001). See Table 7.

Table 7

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<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th><em>F</em></th>
<th><em>p</em></th>
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<td>Using Evidence</td>
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<td>Between Groups</td>
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We used Tukey HSD post hoc tests to conduct pairwise comparisons between all teachers to understand where the significant differences in our ANOVA analyses were coming from. All
means and pairwise comparisons are reported in Table 8 and significant differences between teachers are reported below.

For conducting investigations, Mr. C’s students had the highest mean score, followed by the students of Mr. P, Mrs. S, Mrs. M, and then Mrs. J. Mr. C’s students significantly outperformed Mrs. J’s ($p = .004$) and MY’s ($p = .046$) students. Mr. P’s students also significantly outperformed Mrs. J’s students ($p = .020$).

For analyzing and interpreting data, Mr. C’s students had the highest mean score, followed by the students of Mr. P, Mrs. J, Mrs. S, and then Mrs. M. Mr. C’s students significantly outperformed Mrs. S’s ($p = .002$) and Mrs. M’s students ($p < .001$). Mr. P’s and Mrs. J’s students also significantly outperformed Mrs. M’s students ($p = .006$ and $p = .012$, respectively).

For analyzing and interpreting data, Mr. C’s students again had the highest mean score, followed by the students of Mr. P, Mrs. S, Mrs. J, and then Mrs. M. CF’s students significantly outperformed Mr. P’s ($p = .007$), Mrs. S’s ($p = .002$), JW’s ($p < .001$), and Mrs. M’s students ($p < .001$).

Table 8

*Post Hoc Pairwise Comparisons between Teacher*

<table>
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<tr>
<th>Conducting Investigation</th>
<th>Teacher</th>
<th>$n$</th>
<th>Mean</th>
<th>$SD$</th>
<th>Mr. C</th>
<th>Mrs. S</th>
<th>Mr. P</th>
<th>Mrs. J</th>
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<td>Mr. C</td>
<td>28</td>
<td>1.392</td>
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<td>Mrs. S</td>
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<td>.783</td>
<td>.004*</td>
<td>.851</td>
<td>.020*</td>
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<td>Mrs. M</td>
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<td>.951</td>
<td>.046*</td>
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Discussion

Educational goals to frame science as epistemic practice in classrooms propose helping students understand and participate in the epistemic pursuits of the scientific community (Berland et al., 2016; Lehrer & Schauble, 2015; Stroupe, 2015). Achieving this vision calls for teachers to be knowledgeable and prepared to align the ways of building knowledge in their classrooms with those of the scientific community (Berland et al., 2016). However, effective instruction for teaching science in this way remains under-defined. A crucial step in the effort to teach science as epistemic practice is understanding what it looks like for teachers’ instruction to align with the epistemic practice of science to build a scientific community in classrooms. Our goals in this paper have been to better conceptualize teaching science as epistemic practice and to identify instruction to support students’ apt epistemic performance in science. In particular, we aimed to understand (a) how five teachers provided instruction that aligned with science as epistemic practice, and (b) how their instruction related to students’ understanding of and participation in the epistemic practice of science. Our main findings were as follows:
• Of the five teachers, Mr. C, Mrs. S, and Mr. P made stronger and more frequent connections in their instruction between the epistemic aims of activities and the ideals for how to participate in those activities than Mrs. J and Mrs. M.

• Mr. C, Mrs. S, and Mr. P also talked more consistently over time about epistemic aims and ideals for successful participation than Mrs. J and Mrs. M.

• When teachers made more connections between epistemic aims and ideals and talked more consistently about epistemic aims and ideals, their students tended to have more connected understandings of the epistemic practice of science and were more successful at participating in important aspects of scientific practice.

We discuss these findings with respect to teachers’ (a) support for understanding the connected nature of scientific practice and (b) metacognitive support for learning science as epistemic practice. We also discuss the implications of this work for supporting teachers to teach science as epistemic practice.

**Support for Understanding Connected Nature of Scientific Practice**

Viewing science as epistemic practice forefronts the goals of the scientific community to continually improve understanding of natural phenomena. This view also emphasizes that the processes and procedures used in science are all directed at this pursuit of understanding. Asking questions, conducting investigations, analyzing data, and using evidence are interdependent aspects of scientific practice that are used to develop and refine explanations and models. Learning practice is about understanding the connections and associations between these processes and the norms that guide their use to build knowledge (Shaffer, 2017), and it is important that students understand how these aspects of science cohere and work together so that they can successfully participate in scientific practice (Berland et al., 2016; Erduran & Daghe,
From this perspective, teaching science as epistemic practice should, therefore, support students to understand relationships between the variety of epistemic goals and valued ways for pursing those goals. While researchers have acknowledged the fragmented, disconnected way in which science is often taught in schools (e.g., Erduran & Dagher, 2014; Windschitl et al., 2008), few studies have investigated or conceptualized what it would look like to help students understand science as a connected practice. In this paper, we have taken a novel approach to explore the ways in which teachers’ instruction reflected this connected nature of scientific practice. We have brought together theoretical perspectives of epistemic practice and quantitative ethnography, and prior research in science education in a novel way to analyze how teachers made connections in their instruction that portrayed science as an epistemic practice.

To help students understand science as an epistemic practice driven by goals to explain phenomena and guided by agreed-upon criteria in the scientific community, we were especially interested to see how teachers discussed the epistemic aims and ideals of science in relation to each other. Our findings suggest that talking about epistemic aims and ideals in close temporality may help students see these ideas as related and help them to build understanding of when, why, and how these ideas contribute to the epistemic practice of science. Making connections between how to conduct investigations and the epistemic aims of activities occurred most frequently, and perhaps more naturally, for the teachers (with the exception of Mrs. M who did not make this connection as often as the other teachers). This pattern of teachers talking more about the goals of activities when they were helping students conduct investigations could be due to the purpose of investigations being easier to identify and explain than, for example, analyzing data. This could also be a more familiar connection for teachers to make given that more traditional
approaches to science education have focused on “the scientific method” and following experimental procedures.

In classroom environments with a larger focus on building explanations, more connections might be made to how evidence is used in science. Mr. C and Mrs. S stood out in the ways that they talked about using evidence in relation to conducting investigations and consistently throughout the unit, which suggests that these teachers may have been cultivating classroom environments aligned more closely with the valued ways of building knowledge in science. This focus seemed especially present in Mr. C’s classroom. While Mr. C did not talk as much as the other teachers (indicated by overall fewer lines of teacher talk), the aspects of scientific practice he chose to emphasize with his students highlighted relationships between the epistemic aims of what students were doing, how to conduct investigations, and how to use evidence in science. A central epistemic aim of science is to develop explanations about phenomena (Sandoval, 2015) and the scientific community uses evidence from their investigations to support and convince others of their explanations (Berland & Reiser, 2009; McNeill et al., 2006; Osborne, 2010); so making connections between using evidence, how to conduct an investigation, and the goal or purpose of an activity would reflect a sophisticated understanding of how knowledge and understanding are constructed in science. By framing these aspects of scientific practice as strongly related, Mr. C presented an epistemology of science in his classroom that closely aligned with that of the scientific community. His students significantly outperformed the other teachers’ students in participating in aspects of scientific practice and his students appeared to have the most well connected understanding of how explanations about natural phenomena are constructed in science. Prior work showing the influence of the epistemic environments teachers create on students’ learning and epistemic
cognition (Buehl & Fives, 2016) suggests that Mr. C’s framing of science likely played an important role in his students’ understanding of and participation in science as an epistemic practice.

While teachers discussed and made connections between epistemic aims and ideals, this support did not seem to be a focus of instruction, and many students did not develop an understanding of the connected nature of scientific practice. The curriculum teachers used in this study was intentionally designed to present all of the activities as connected and in service of students’ final scientific explanations and models of ecosystems in their compost designs. However, teachers did not always highlight these connections for students. This raises questions about how to help teachers make the connected nature of epistemic practice more prevalent in their science instruction.

Integrating the ways in which the scientific community constructs knowledge and understanding into classrooms is a central feature of meaningfully engaging students in the practice of science (Berland et al. 2016). Our findings suggest that making connections between what students are doing and the epistemic pursuits of building explanations and understanding in science may help student develop a strong and connected understanding of how knowledge in constructed in science. Teachers play an essential role in establishing the valued ways of building knowledge in a classroom that impact students’ learning and their understanding of the epistemology of a domain (Buehl & Fives, 2016). Creating epistemic environments that reflect the connected nature of scientific practice shows promise for supporting students’ learning and successful participation in the epistemic practice of science. Our results suggest that teachers might also need support to understand and more purposefully discuss these connections with their students. More research is needed to better understand teachers’ knowledge about these
relationships and whether making these connections is something teachers are actively thinking about in their instruction.

**Metacognitive Support for Learning Science as Epistemic Practice**

Our findings also suggest that effectively teaching science as practice goes beyond engaging students in epistemologically meaningful activities. The theoretical notion of practice (Wenger, 1998) and the idea of apt epistemic performance (Barzilai & Chinn, 2018) highlight that engaging in activity is important. Engaging students in activities that pursue valued epistemic aims of science and ask students to meet criteria held by the scientific community is important, but may not help students understand what they are doing and why it is important (Sandoval, 2005). Supporting students to develop metacognitive awareness or knowledge about how and why to engage in particular activities is thought to be important (Barzilai & Chinn, 2018; Barzilai & Zohar, 2014; 2016; Chinn & Sandoval; 2018).

All five teachers in this study taught the same curriculum that engaged students in epistemologically meaningful activities. All of the activities within the compost unit were purposefully and thoughtfully designed to engage students in the valued processes of science to pursue epistemic goals of creating evidence-based explanations and models (valued epistemic products in science). What differed between classes was not the types of activities students engaged in, but the ways in which the teachers framed these activities and supported students to understand how and why to successfully participate. Our analyses showed that there were differences in the ways in which the teachers discussed the “why” and “how” of participating in science as practice. Previous research suggests that there is little evidence that simply engaging students in inquiry, modeling, or argumentation activities leads to understanding the epistemic underpinnings of how and why scientific knowledge in constructed in these ways (Sandoval,
Making the epistemic goals of science and how to achieve those goals explicit for students has been shown to help students better understand and engage in scientific inquiry (McNeill & Krajick, 2008; Sandoval & Reiser, 2004). For instance, students’ successful use of data to back up their claims when constructing explanations may rely on their understanding of the “why” or epistemic importance of using evidence is important in science (Sandoval & Millwood, 2005). Additionally, McNeill and Krajick’s (2008) investigation of how teachers’ instructional practices affect students’ ability to construct scientific explanations has illustrated the importance of discussing the rationale and purpose of constructing explanations in science. In their study of teachers’ different uses of instructional practices, they found that discussing criteria for how to construct science explanations was only beneficial when teachers also explained the rationale for constructing an explanation to convince an audience about a claim. Our findings in this study align with this prior research and highlight the need for teachers to support a meta-level understanding of what the goals of scientific practice are and how and why certain criteria should be met in order to achieve those goals.

Conclusions and Future Directions

The growing emphasis on practice in science education calls for teaching students how to build knowledge and explanations about the natural world (Ford, 2015; Kuhn, Arvidsson, Lesperance, Corprew, 2017; Osborne, 2014). To answer this call, teachers must be well equipped with instructional strategies to support both students understanding of and their participation in science as practice. Creating opportunities for students to engage in the authentic work of the scientific community is crucial (Berland et al., 2016; Lehrer & Schauble, 2015; Stroupe, 2015), but our work suggests that supporting students to understand why and how to successfully participate in this work is also necessary. Discussing the rationale and purpose for the processes
and standards for practice seems to be a crucial aspect of instruction that may be overlooked in classrooms. While the importance of and connections between activities may be obvious to teachers, students likely need guidance to understand these.

Although we saw teachers discuss epistemic aims and ideals of science and make connections between these aspects of practice, this support was still limited. Teaching science as epistemic practice was not a central focus. There were moments, even extended periods of time, where teachers seemed focused on engaging students in the scientific pursuit of developing explanations and helping students see their efforts as participating in scientific practice. But even in the classrooms where teachers made more connections between and talked more consistently over time about epistemic aims and ideals, ensuring that students learned science content and completed activities often prevailed. So, while this study sheds light on promising instructional moves to teach science as epistemic practice, there is much work to be done to help teachers readily enact such instruction and shift the emphasis in science classroom towards practice, as called for by education standards (NGSS Lead States, 2013; NRC, 2012) and many researchers (e.g., Ford, 2015; Lehrer & Schauble, 2015; Osborne, 2014).

Using the lens of epistemic aims and ideals (Barzilai & Chinn, 2018), we have conceptualized specific ways that teachers might talk about the epistemic goals and criteria for building knowledge in science and identify these in five teachers’ classroom instruction. We believe this provides a useful contribution to the field of learning sciences and education researchers in science and other domains. Barzilai and Chinn’s recent theoretical framework of epistemic practice offers a useful and generative perspective for thinking about what and how students should about the epistemic practice of a domain (2018). However, there are a few examples in the existing literature of applications of this perspective. Our work provides a model
for applying this perspective to analyzing instruction for epistemic practice and makes a novel connection between this perspective and an analytical tool developed for quantitative ethnography – a combination we believe could be quite powerful for future research.

Our work also offers insights into ways that teachers could support students’ understanding of and participation in the epistemic practice of science. However, open questions remain about teachers’ understanding and intentionality to enact this type of instruction and how teachers can make this instruction more central in their classrooms. Investigating whether and how teachers think about teaching science as epistemic practice is an important next step in being able to support teachers to create communities of scientific practice in their classrooms.
CHAPTER 4

Teachers’ Understanding about Teaching Science as Epistemic Practice

Goals for teaching science as epistemic practice have become prominent in science education, whereby students learn to participate in the authentic, epistemologically valued efforts of the scientific community to explain natural phenomena (Lehrer & Schauble, 2006, 2015; National Research Council, 2012). Making this vision a reality requires that teachers are well supported to understand the epistemic practice of science and specific ways to help students understand and participate in this practice in their classrooms. While the curricula and instructional materials used in classrooms are important, teachers play an essential role in how and what students learn (Remillard, 2005; Stein, Remillard, & Smith, 2007). Teachers’ knowledge, among other contextual factors, influences how they enact a particular curriculum (Remillard, 2005). There is also increasing evidence that teachers’ epistemic cognition plays a critical role in their approaches to teaching and in the learning goals they set for their students (Buehl & Fives, 2016; Kang, 2008; Lunn Brownlee, Ferguson, & Ryan, 2017; Yadav, Herron, & Samarapungavan, 2011). Teachers’ views of how knowledge and understanding are constructed have been shown to influence their teaching and the learning environments they create for their students (Bråten, Muis, Reznitskaya, 2017; Lunn Brownlee et al., 2017; Tsai, 2006). Thus, it is essential to understand and support teachers’ thinking about science as epistemic practice so they are well prepared to support their students. As Buehl and Fives (2016) have said, “the need for teachers in engage in epistemic cognition is exponentially higher than it is for students as teachers both learn and design context for the learning of others” (p. 248).

In the context of science education, it follows that teachers’ views and understanding of how knowledge is constructed in science would influence how they create communities of
scientific practice in their classrooms. A central goal for teaching science as epistemic practice is to more closely align the ways of building understanding in science classrooms with those of the scientific community (Berland et al. 2016), fostering communities of scientific practice in classrooms. Aligning the epistemic aims (i.e., goals for building knowledge) of the classroom community with the epistemic aims of the scientific community seems essential in this effort. This can partially be accomplished by designing activities and curricula that pursue the epistemic aims of science to develop explanations or explanatory models about the natural world. But understanding science as epistemic practice also involves awareness and metacognition about these aims, and how and why various epistemic ideals and processes are in service of these aims (Barzilai & Chinn, 2018). Based on the premise that teachers’ epistemic cognition influences their teaching (Bråten et al., 2017; Buehl & Fives, 2016; Lunn Brownlee et al., 2017), in order to create classroom communities that align with the epistemology of science, it is important that teachers understand these features of the epistemic practice of science and how to integrate this view into their instruction. Only by first developing understanding about the epistemic practice of science themselves can teachers intentionally support this thinking for their students.

To help teachers successfully enact instruction for science as an epistemic practice, we need to know more about how teachers think about science and teaching science in this way. Reflection has been shown to be a powerful way to elicit and improve epistemic cognition and to promote change in teachers’ practice (Bråten et al., 2017; Lunn Brownlee et al., 2017). Asking teachers to reflect on their own instructional practices can help to elicit teachers’ conceptions of their own practice and their conceptions of the epistemic nature of scientific practice. We know little about how teachers think about the epistemic aims of science or how they view the activities their students participate in as contributing to constructing knowledge as a scientific
community. We know even less about how teachers think about teaching these important ideas to their students. Our goal in this chapter has been to elicit teachers’ knowledge about teaching science as epistemic practice through reflection on their own teaching to better understand the instruction that occurs in their classrooms and how to support teachers’ learning in the future.

In this paper, we explore how teachers think about teaching science as epistemic practice, particularly how they understand and reflect on their own teaching as supporting participation in the epistemic practice of science. We conceptualize the epistemic practice of science through the lens of the Apt-AIR framework, which describes epistemic practice from a situated, context-specific perspective in terms of epistemic aims, ideals, and reliable processes (Barzilai & Chinn, 2018). Briefly, epistemic aims can be thought of as the goals of a community to develop epistemic products (e.g., knowledge, understanding, explanations), epistemic ideals are the criteria or standards held for developing and evaluating those products, and reliable epistemic processes are the procedures or ways in which communities develop those products. In Chapter 2, we have described these aspects of epistemic practice and applied them to the practice of science. We use this prior work as a basis for our discussion of science as epistemic practice here. This chapter is organized as follows: first, we discuss the role of teachers’ knowledge and teachers’ epistemic cognition in classrooms that has influenced why and how we investigated teachers’ thinking. Then, we describe our specific research questions, methods for interviewing teachers, and our findings about teachers’ conceptions. We conclude by discussing the implications of this work and offering recommendations for supporting teachers’ understanding of teaching science as epistemic practice in their classrooms.

**Theoretical Background**

**The Role of Teachers’ Knowledge and Epistemic Cognition**
Previous research on teacher learning and professional development highlights the need to understand what teachers know and how they use that knowledge in the classroom (Ball, Thames, & Phelps, 2008; Borko, 2004; Davis & Krajick, 2005). It is generally accepted that teachers need content knowledge of the subject matter they are teaching and pedagogical knowledge about how to teach (Ball et al., 2008; Davis & Krajick, 2005). In addition, teachers need knowledge of the most useful ways to represent and explain specific content, the common conceptions and misconceptions students have about that content, and why certain content knowledge is accepted as true – this is known as pedagogical content knowledge (Ball, Thames, & Phelps, 2008; Davis & Krajick, 2005; Shulman, 1986). Davis and Krajick (2005) further described the importance of pedagogical content knowledge for disciplinary practices; they have argued that teachers need knowledge of “how to help students understand the authentic activities of a discipline, the ways knowledge is developed in a particular field, and the beliefs that represent a sophisticated understanding of how the field works” (p. 5). This means that teachers need particular knowledge about how to teach the epistemic nature of disciplinary practice. Thus for science, teachers need knowledge about how to teach the epistemic nature of scientific practice.

Knowledge of the authentic activities of a particular discipline and how knowledge is developed in that discipline has also been described as epistemic metacognitive knowledge (Barzilai & Chinn, 2018; Barzilai & Zohar, 2016). Epistemic metacognitive knowledge includes knowledge about the components of an epistemic practice (i.e., the epistemic aims, ideals, and processes of knowledge construction and justification), and when, how, and why to apply such components (Barzilai & Zohar, 2016). While much of the discussion about epistemic metacognitive knowledge has related to students’ learning (Barzilai & Zohar, 2014; 2016), it
follows that teachers also need this knowledge in order to support students’ epistemic metacognitive knowledge. Teachers’ epistemic metacognitive knowledge about the epistemic practice of science entails, again, knowledge of the epistemic aims and goals of science (e.g., explaining natural phenomena), the epistemic ideals or criteria that are used to create and evaluate epistemic products (e.g., using sufficient evidence to support an explanation), and the epistemic processes used in science to develop such products (e.g., conducting experiments and argumentation). The meta-level nature of this knowledge entails that teachers are aware of and recognize the epistemic nature of scientific practice. Further, epistemic metacognitive knowledge includes knowledge of the relationships and connections between these components. This connected understanding of the epistemic components of scientific practice and the relationships between them is crucial for seeing science as a set of interdependent epistemic processes that are guided by particular criteria to achieve the goal of better explaining our world.

Influence of Teachers’ Epistemic Cognition on Instruction. There is growing evidence that teachers’ epistemic cognition influences their approaches to instruction (Bråten et al., 2017; Buehl & Fives, 2016; Kang, 2008; Lunn Brownlee et al., 2017; Tsai, 2006; Yadav et al., 2011). Teachers’ thinking about epistemic aims and the processes for achieving those aims can facilitate or constrain their implementation of instruction. For example, the extent of teachers’ constructivist views of building knowledge has been shown to influence their willingness and ability to adopt more constructivist stances in their classrooms and engage their students in argumentation and collaborative knowledge building (Lunn Brownlee et al., 2017; Lunn Brownlee, Schraw, Berthelsen, 2011; Maggioni & Parkinson, 2008; Ryu & Sandoval, 2012; Tsai, 2006). More specifically, Tsai (2006) found coherence between teachers’ beliefs about scientific knowledge, beliefs about student learning, and their instructional approaches – teachers who had
constructivist beliefs about science knowledge also had constructivist beliefs about students learning and implemented more constructivist instructional practices in their classrooms. This work emphasizes the key role that teachers’ epistemic thinking about science plays in their instruction. Buehl and Fives (2016) have argued a similar idea that teachers’ instruction is guided by the epistemic aims they hold for their students. They highlight that teachers who understand and hold epistemic aims for students (i.e., building understanding and explanations) are more likely to promote deep understanding, collaborative knowledge building, and argumentation in their classes, while teachers who hold non-epistemic aims (i.e., high test scores) might focus on correct answers and a singular correct way to solve a problem. As such, having well-formed knowledge about epistemic aims seems crucial for teachers to be able to guide students in epistemic thinking and participating in epistemic practice.

The evidence that teachers’ epistemic cognition corresponds to, and likely impacts, their instruction and the learning environments they create for their students is crucially important when considering how teachers’ instruction aligns with the epistemic practice of science. This prior work suggests that for teachers to implement a perspective of science as practice and foster communities of scientific practice, it would be important for their aims for students to align with the epistemic aims of science. Further, their understanding about the epistemic ideals and processes of scientific practice and the relationships between them would influence the ways in which they teach science as epistemic practice. Thus, it is crucial that teachers understand science as an epistemic practice aimed at developing knowledge and explanations about the world, so that they can frame science in this way for their students.

While teachers’ epistemic cognition plays an important role in their instruction, teachers’ knowledge, beliefs, and intended actions are not always reflected in their actions in the
classroom. There is growing evidence in studies on epistemic cognition of discrepancies in the epistemic knowledge exhibited through self-report versus actual practice (Chinn & Rinehart, 2016; Elby, Macrander, & Hammer, 2016; Lunn Brownlee et al., 2017; Sandoval, 2005). With respect to teachers, Elby and colleagues (2016) state, "a common finding is that the beliefs and vision of teaching and learning expressed through interviews/surveys is more student-centered and epistemologically sophisticated than the beliefs/visions enacted in the teachers' classroom practice" (p. 118). So, while teachers might have an understanding of the epistemic nature of scientific practice, this knowledge may not translate into instruction that supports students’ understanding.

Prior work has shown that the instructional support that teachers provide may not reflect their knowledge or intentions due to a variety of environmental and contextual factors (Elby et al., 2016; Remillard, 2005). Research on epistemic cognition and practices specifically suggests that such discrepancies could be due to "classroom and curriculum constraints, teachers' lack of confidence of skill in implementing student-centered lessons, or...contextual sensitivity" (Elby et al., 2016, p. 118). Others have proposed possible constraints including “social factors, situational constraints, teachers’ level of experience, intentions, lack of self-efficacy in being able to carry out more constructivist approaches, perceptions of students’ ability, and a reliance on district-mandated curriculum and teaching strategies” (Bråten et al., 2017; citing Buehl & Beck, 2015; Muis & Foy, 2010). These general constraints are informative, but little is still known about the specific constraints or challenges that teachers face in supporting students to successfully participate in the epistemic practice of science. Recently, Bråten and colleagues called for more in-depth qualitative investigations to identify "external and individual factors that either support or preclude teachers from effectively calibrating their epistemic cognition with advocated
classroom practices” (Bråten et al., 2017, p. 164). We aim to help answer this call in the context of science teaching in our work.

More empirical research is needed to better understand teachers’ epistemic cognition and how it relates to their own teaching practices (Buehl & Fives, 2016; Elby et al., 2016; Lunn Brownlee et al., 2017). In science education, there are many open questions about how teachers’ knowledge influences their instruction for science as epistemic practice. How does teachers’ understanding of the epistemic practice of science relate to their instruction? What are the discrepancies between teachers’ thinking and their instruction, and what are the challenges teachers face in the context of teaching science as epistemic practice? How can teachers be supported to align their instruction with the epistemic practice of science? Is it an issue of understanding the epistemic nature of scientific practice or translating their understanding into instruction? Better understanding teachers’ knowledge about the epistemic practice of science is a necessary first step in being able to promote teacher learning and help teachers apply essential knowledge during classroom instruction.

Findings of discrepancies between teachers’ thinking and instruction (Elby et al., 2016) also raise methodological implications for assessing and analyzing teachers’ epistemic metacognitive knowledge. These findings suggest that understanding of teachers’ epistemic metacognitive knowledge requires both self-report measures and analyzing how this knowledge is reflected and used in practice in their classrooms. Thus, investigating teachers’ understanding both via their self-report and their actions would seem to provide important insights into their understanding of epistemic practices and approaches to teach these practices. In the previous chapter, we investigated teachers’ approaches to teaching science as epistemic practice through their actions, so our focus here has been on teachers’ self-report through interviews.
The Present Study

Based on our prior work investigating teachers’ actions and instruction in classrooms, the current study provided a complementary investigation into teachers’ thinking to better understand their approaches to teaching science as an epistemic practice. In chapter 3, we have analyzed teachers’ instruction for science as an epistemic practice, looking specifically at how five middle school science teachers talked about epistemic aims and epistemic ideals of science with their students. We found that three of these teachers made stronger connections between and talked more consistently over time than the other two teachers about epistemic aims of the activities students were doing and various epistemic ideals for how to participate in scientific practice. We also found that these three teachers’ students appeared to understand and participate more successfully in aspects of scientific practice than students in the other teachers’ classes. Based on these findings, we were curious about how these three teachers conceptualized science as epistemic practice and how they viewed their instruction as supporting this perspective of science in their classrooms. We aimed to answer the following questions:

- How do teachers conceptualize science as epistemic practice? How do teachers conceptualize the epistemic aims, ideals, and processes of science?
- How do teachers understand their own instruction as supporting students to learn science as epistemic practice? How do they approach teaching students to participate in and understand the epistemic aims, ideals, and processes for developing knowledge in science?

Methods

We conducted a multiple-case study to investigate three teachers’ understanding of teaching science as epistemic practice. We used a descriptive and qualitative approach with a
small sample in order to provide an in-depth account of the teachers’ conceptions and understanding. Little is known about how teachers think about or reflect on their own teaching about science as epistemic practice, so we chose to conduct a detailed investigation with a few teachers to understand the nuances of their thinking.

**Participants**

The participants in this study were three 8th grade science teachers, Mr. C, Mrs. S, and Mr. P. The teachers were from two public middle schools in the same city and district in the Midwestern United States. Mr. C and Mrs. S both taught at School A, which was slightly more diverse and economically disadvantaged than School B where Mr. P taught (see Table 1). Information about each teacher’s educational background, teaching certification, and years of teaching is provided in Table 1. Of note, all of the teachers had master’s degrees and 11 or more years of science teaching experience. Mr. C and Mr. P both had degrees in science, which might suggest strong content knowledge in science. While Mr. C and Mr. P had predominately taught 8th grade science during their careers, Mrs. S had recently returned to teach 8th grade after teaching 6th grade science for eight years. She had many years of science teaching experience, but less than Mr. C and Mr. P at the 8th grade level. Additionally, Mr. C was on the curriculum committee for middle school science in the district and was a leader in convincing other teachers and administrators to align their district standards and assessments with the Next Generation Science Standards’ (NGSS Lead States, 2013) focus on the practice of science. Thus, Mr. C was quite familiar with thinking about science as practice.

The teachers were recruited as participants in a larger research project through which they taught a design-based, inquiry science curriculum, discussed next in the context. These three teachers were chosen for the current study because we were interested in how experienced
science teachers who had demonstrated promising approaches to teaching science as epistemic practice in our previous work thought about and reflected on this type of instruction.

Additionally, a key feature of the interviews we conducted with teachers involved showing them videos of themselves teaching from a prior year of the research project, so we chose to interview teachers of whom we had classroom videos and who were still in touch with the project team.

Table 1

**Participating Teacher Information**

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Educational Background</th>
<th>Teaching Certification</th>
<th>Years Teaching</th>
<th>School</th>
<th>School demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. C</td>
<td>BS: Child Development/ Elementary Education; MS: Natural Resources</td>
<td>Grades 1-8</td>
<td>18 total; 14 science (3 - 7th; 11 - 8th)</td>
<td>School A</td>
<td>- 66% white, 19% Hispanic, 6% black - 59% economically disadvantaged</td>
</tr>
<tr>
<td>Mrs. S</td>
<td>BA: Elementary/ Middle Education (science &amp; math); MS: Professional Development</td>
<td>Grades 1-9</td>
<td>11 science (8 - 6th; 3 - 8th)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mr. P</td>
<td>BS: Ecology/ Field Biology; MS: Education</td>
<td>Grades 6-12 Biology and Broadfield Science</td>
<td>12 science (all 8th)</td>
<td>School B</td>
<td>- 78% white, 10% Hispanic, 5% black - 44% economically disadvantaged</td>
</tr>
</tbody>
</table>

**Context**

Mr. C, Mrs. S, and Mr. P were part of a larger research project in which they taught a 12-week design-based life sciences unit on energy and matter transformation in ecosystems. For the current study, they were interviewed in the spring after having taught the unit for two years.

Videos clips of the teachers from the first year of the unit were incorporated into the interviews as reflective prompts, described in more detail later. The interviews were conducted by the first author with each teacher individually in his or her classroom.
The unit that teachers taught presented students with a design challenge to create compost that broke down quickly and contained nutrients to help address the global issue of increasing amounts of waste in landfills. Each activity within the unit engaged students in scientific practice to learn relevant content in order to solve this challenge. These activities consisted of whole class discussions and small group work through which students developed research questions, conducted experiments and second-hand research investigations, analyzed data, constructed scientific explanations, and made arguments about how to solve their challenge. As part of the larger research project, all teachers participated in professional development about implementing the curricula and facilitating student-centered, inquiry-based approaches to science. This professional development was not directed at developing knowledge of or instructional strategies for the epistemic aims, epistemic ideals, or reliable epistemic processes of science that were analyzed in this research; thus, this was not a study of teachers’ uptake of particular knowledge or instructional practices, but rather an investigation into their current understanding.

**Data Source: Teacher Interviews**

The first author conducted semi-structured interviews with each of the teachers to investigate their (a) epistemic metacognitive knowledge of epistemic aims, epistemic ideals, and reliable epistemic processes in science, (b) approaches to supporting students’ learning of science as epistemic practice, and (c) understanding of their own teaching as supporting students’ learning. We designed the interview protocol based on the Apt-AIR model of epistemic cognition and practices (Barzilai & Chinn, 2018; Chinn & Rinehart, 2016; Chinn et al., 2014) to elicit teachers ideas about the epistemic aims and values, epistemic ideals, and reliable epistemic processes of science (see Appendix for full protocol). Questions were designed to gain insight into teachers’ understanding about the epistemic nature of the practice of science and their
approaches to teaching students about this epistemic nature. The interviews were semi-structured and guided by teachers’ responses. The first author based follow-up questions on teachers’ responses in the moment to deeply probe their understanding. Given that little is known about teachers’ epistemic metacognitive knowledge about science as epistemic practice or how to elicit this knowledge, we took an exploratory approach with our questioning guided by teachers’ responses.

First, we situated the interview questions and made them more concrete for teachers by asking teachers to think about a recent unit they taught in their classroom. This unit provided context for the teachers rather than asking abstract questions. We elicited teachers’ knowledge about the epistemic aims and values of science by asking teachers what they most wanted students to learn in science and why they thought it was important for students to learn those ideas or skills. Follow-up questions included asking teachers why they thought learning particular skills, processes, or content were important; whether and how they conveyed their goals to students; whether and how they discussed with students why these ideas were important to learn; and what goals teachers hoped students set for their own learning in science.

Next, we elicited teachers’ ideas about epistemic ideals and reliable epistemic processes in their science classrooms, that is, what students needed to do to achieve goals of constructing knowledge and explanations in science. We asked teachers what processes or skills they thought were important for students to learn or use to develop their scientific knowledge. We situated this question by referencing the recent unit teachers had described already and asked them to discuss what processes, skills, or practices (we used “practices” here because it was a familiar and useful term for teachers, although we view science as an overarching practice) were important for students to use in that unit. We then probed teachers about epistemic ideals related to these
processes that they mentioned with follow-up questions about how they might help students understand the criteria and standards for participating in these processes and why these processes or specific criteria were important in science. We also asked teachers what challenges they faced when trying to support students to learn these aspects of scientific practice. We asked these follow-up questions specifically about the epistemic processes of asking questions, conducting investigations, analyzing and interpreting data, and using evidence based on our prior work conceptualizing the epistemic ideals related to these processes in science.

**Reflections on videos of their own teaching.** In the final part of the interviews, we asked teachers to reflect on videos of their own teaching. Epistemic cognition and thinking can be both elicited and developed through reflection. Explicit reflection on epistemic beliefs is a powerful tool for understanding and changing epistemic thinking (Bråten et al., 2017). Lunn Brownlee and colleagues (2017) have focused on the key role of epistemic metacognition (which they frame as reflexive thinking about epistemic cognition) in changing epistemic cognition. They have argued that improving epistemic cognition first requires teachers “making the epistemic aims and reliable processes explicit,” deliberating about how their own teaching practices align with epistemic aims and reliable processes, and deciding how to resolve discrepancies between these (Lunn Brownlee et al., 2017, p. 6). Having teachers reflect on their own epistemic beliefs and thinking in the context of their teaching may help elicit their ideas about epistemic aims, ideals, and processes, and may help teachers change their epistemic thinking in ways that influence their instruction. Our main goal in these interviews has been on the former, recognizing that our methods may also provide insights into facilitating the later.

We showed each teacher two pre-selected video segments of their own teaching that we had collected from a prior school year. We elicited teachers’ ideas about how they supported
students’ understanding, what they might do differently, and what challenges they perceive in supporting students to successfully participate in and understand the science as an epistemic practice. The video segments were selected from a larger set of videos and contained positive examples of teachers’ instruction and missed opportunities for instruction related to understanding the epistemic aims, ideals, or processes of science. This reflective portion of the interview was designed to provide further insights into teachers’ understanding of instructional moves to help students participate in and understand science as epistemic practice. Given the delay between the interviews and the videos, our goals were not to directly compare teachers’ planned versus enacted instruction. Rather, we were interested in how teachers reflected on their own instructional practice and what insights about their approaches to teaching science as epistemic practice might be uncovered by this reflection.

The interviews were audio recorded for later transcription and lasted 1.5 hours for Mr. C, 1.6 hours for Mrs. S, and 1.4 hours for Mr. P.

Analysis

We took a descriptive, qualitative approach to analyzing the interviews. We used content analysis techniques (Lune & Berg, 2017) to identify themes and patterns in the data and used critical incidents techniques (Flanagan, 1954) to identify key statements that stood out in the interviews. We first transcribed the interviews. The first author read through the transcripts several times to annotate and summarize teachers’ responses. From the transcripts, annotations, and summaries, themes and patterns in teachers’ responses were identified. We looked for teachers’ responses to particular planned questions from the interview that targeted our research questions, but we also wanted to be open-minded and unbiased to what else the teachers were conveying in their comments. Thus, we iteratively looked for themes and patterns in the data
with respect to a priori categories that would help us answer our research questions and looked for emergent themes and patterns from the data. From this process, we developed five main categories and organized teachers’ ideas into these categories: a) what teachers wanted students to understand about scientific practice; b) helping students understand why aspects of scientific practice are important; c) helping students understand how to participate in the epistemic practice of science; d) teachers’ reflections on their own teaching; and e) challenges to teaching science as epistemic practice.

Results

We examined the interviews with Mr. C, Mrs. S, and Mr. P for their conceptualization about helping students understand:

a) what they wanted students to understand about scientific practice,

b) why aspects of scientific practice are important, and

c) how to participate in those aspects of scientific practice.

We also examined the interviews for:

d) teachers’ reflections on their own teaching and

e) challenges to teaching science as epistemic practice.

The results are organized with respect to these ideas. We present main themes that we saw across teachers’ responses and highlight notable contrasts between the teachers, in each of these categories. We provide descriptive accounts of the conversations that took place during the interviews and include illustrative examples as evidence of the themes and patterns we identified.

We believe these examples to be representative of the data.

What Teachers Wanted Students to Understand about Scientific Practice
We first looked at what teachers thought was important for students to learn about scientific practice. We were particularly interested in whether and how teachers discussed students pursuing epistemic aims in their science classrooms – what did teachers want students to understand and be able to do in science and how did these align with the epistemic aims of science?

It was clear that all three teachers valued students pursuing epistemic aims in their science classes and that they cared more about students understanding the epistemic pursuit of science than learning science content. Rather than simply learning information, the teachers wanted students to learn how that information was developed. We saw evidence of this desire for students to pursue epistemic aims when we asked them what the most important things they wanted their students to learn in science were. Mr. C adamantly said, “It has nothing to do with standards or content,” and Mr. P similarly stated, “It wouldn’t be the standards and everything else.” All three teachers acknowledged that students often forgot information and had constant access to content on their phones and the internet, so learning science content was not what teachers valued most. Instead, the goals they had for their students centered on learning how to think and reason about information to solve problems in science. Mr. P described this as, “to not worry about the whats, but more the whys and the hows. That’s more important to me.” Mrs. S, likewise, highlighted that while she “use to think that they had to know all the facts,” she had made a change in her teaching and now thought, “It’s not about that. It’s about the process and it’s the thinking.” More specifically, all the teachers talked about wanting students to learn how to ask questions, how to solve problems and answer questions, and how to evaluate information. These three main ideas reflected a valued focus on the ways in which knowledge is constructed in science. Teachers shared this broader goal that students learn about the epistemic aims of
science, but what they emphasized and their conceptions of what specifically to convey to students were different. In this section, we highlight the epistemic aims on which each teachers focused.

Mr. C talked about wanting students to learn how to ask questions, but he more strongly emphasized thinking critically, problem solving, and evaluating information to find answers to those questions in science. He described thinking critically as being able to look at problems from different angles, think creatively, and recognize that there are multiple ways to solve problems. He talked specifically about his goals for students to learn how to “have a scientific discourse…and use your claims and your evidence and your reasoning” in order to solve problems and develop answers collaboratively. Collaboration and communication were important aspects of solving problems in science to Mr. C. Learning how to evaluate information was also key. Mr. C talked about wanting his students to be scientifically literate, which he defined as being able to evaluate information and make educated decisions based on that information and to question peoples’ claims rather than simply believe what they say. He strongly valued students learning to evaluate information and made this clear several times in the interview. For instance, when talking about the “science practices” focused benchmarks his school district had adopted (which he had helped craft based on the Next Generation Science Standards), he said that he most valued evaluating and communicating information. Later, he said, “I think the most important thing, scientifically, for them to walk away with is the evaluation piece. How can they look at things and evaluate them using the tools we have given them.” As shown through these examples, Mr. C wanted his students to pursue epistemic aims in science and understand how evidence and evaluation were critical in this effort.
Mrs. S emphasized students learning to evaluate information. The first thing that Mrs. S mentioned when we asked her what she most wanted her students to learn in science was to evaluate and be critical of information. She said, “I want them to be able to look at something and not take it for face value… I want them to learn that you can’t just read something and then just automatically believe it.” This type of evaluation was how Mrs. S described critical thinking. She gave several examples of how her students are quick to accept information as truth and talked about using the real world examples in her students’ lives (e.g., rumors in social situations at school, news stories, and social media) to help them understand the importance of evaluating information in science. Mrs. S described activities she did with her students to look at ways scientists have been wrong throughout history and how data can be misrepresented or unreliable, with the goal of helping her students get into a habit of questioning others’ claims. She described:

Mrs. S: Just because there is data, like we did that little activity, doesn’t mean that it is necessarily true. Like where did they get the data, how did they get the data? That kind of thing. So that is something that I am always working on my kids.

Here, she expressed wanting her students to question where data came from and how it was gathered. Additionally, she talked about wanting students to understand how to ask and answer questions. For Mrs. S, the idea of, “What’s that question and how are you going to go about answering it?” stemmed from her view that “science, so much, is trying to explain our world.” When describing how she wanted students to ask questions, she focused on students developing habits of asking questions and questioning other people’s claims – this tied back to her emphasis on evaluating information.
Like Mr. C and Mrs. S, Mr. P thought it was most important for students to learn how knowledge and understanding was constructed in science. He emphasized wanting his student to “learn how to learn” – to learn how to think, reason, and understand what questions to ask in science. Mr. P focused on wanting students to understand that science was about gaining evidence and that theories were built over time as evidence accumulated. He spent a lot of time at the beginning of the school year talking with student about scientific theories: what they were, how they were developed, and the important role of evidence. Mr. P was especially concerned that many of his students came into his class with a view that scientific theories were “just something that we are still not sure about.” He wanted students to understand that theories are our current best explanations for how things work, and that theories are strengthened overtime by more evidence. This was a key idea about the epistemic nature of scientific practice that Mr. P thought was important for his students to learn. The other main epistemic idea that he focused on was asking questions. He discussed wanting students to understand what types of questions to ask in order to find the information they needed to solve a problem, rather than just searching for surface level answers in science. In line with his desire for students to learn how to ask questions, he wanted students to want to ask questions – to be curious and have a sense of “wonder and awe” in science.

While Mr. C, Mrs. S, and Mr. P emphasized slightly different aspects of scientific practice, their comments reflected important epistemic aims that they wanted students to pursue in science. Their focuses on wanting students to be able to ask questions, evaluate information, and come to their own decisions in order to solve problems all aligned with epistemic aims of the scientific community. Asking questions about natural phenomena and then developing explanations to answer those questions is key to the practice of science. Evaluating and
critiquing information also play a central role in the pursuit of developing and improving explanations through scientific argumentation. However, although all three teachers expressed wanting their students to pursue epistemic aims in science, there was some misalignment between these epistemic aims and the aims that they thought about their students adopting for their own learning in science.

**Teachers’ thoughts about their students’ aims.** To further understand how teachers conceptualized their students pursuing epistemic aims in science, we asked the teachers what goals they hoped their students set for themselves and their own pursuit of knowledge in science class. To create communities of scientific practice in classrooms, it would be important for students to adopt epistemic aims in science and knowledgeably strive to develop explanations about phenomena. While all three teachers had described wanting their students to pursue epistemic aims in class that aligned with those of the scientific community, we found some differences when it came to describing epistemic aims from the perspective of their students. In particular, Mrs. S and Mrs. P did not necessarily see learning how to think critically, evaluate information, solve problems, and ask questions as the aims that their students would adopt, whereas Mr. C did.

Mr. C had a clear vision of the mindset that he wanted his students to adopt in science, which corresponded to the epistemic aims he wanted students to learn in his class. He said without hesitation:

Mr. C: My biggest goal is that I hope they go into high school with the mindset of “here are these problems, here are these issues, here are things we need and *can* solve if we have, if we can find the right evidence, provide some reasoning and go from there.”
This reflected a common idea we saw throughout Mr. C’s interview of framing teaching science in terms of teaching students how to solve problems and answer questions. It was evident that he wanted students to adopt a problem solving mindset and feel empowered to gather evidence and reason through a problem.

Mrs. S, on the other hand, had described wanting students to learn how to think critically and evaluate information so they could build explanations in science, but she did not necessarily see those as aims her students would adopt for themselves. Instead, she talked about wanting students to be open-minded and willing to try, even when they did not enjoy what they were learning. She said:

Mrs. S: I don't think that they know that they need to think critically… Does that make sense? Like I don't think they walk in and think, “Wow, I’m going to think critically today.” But if their goal is to at least try, and attempt science, and have an open mind, then my goal might be able to come in.

Here, we saw Mrs. S acknowledge a difference between the epistemic aims that she wanted to foster in her classroom (evaluating information and thinking critically) and the aims that she hoped students would pursue (having an open-mind and being willing to try). She had a, perhaps, more practical goal she hoped students would adopt, and she saw this goal of open-mindedness as being in service of the epistemic aims she really wanted students to learn.

Finally, when we asked Mr. P about the aims he wanted students to set for themselves, he said that he had not thought much about this:

Mr. P: I don’t know if I’ve actually even thought about that. That's probably something I should do. I’m just hoping honestly that they start to, find science more interesting. I’m hoping that they come out of this wanting to take more science classes, that they are
enjoying what they are doing. And from there, maybe I need to think about that more. I honestly don’t think much about what goals the kids have for their learning in that process. Something I could improve on.

Mr. P had clear ideas earlier about wanting his students to learn how to learn, ask questions, and understand how evidence is used to build theories in science. But thinking about goals from his students’ perspective was not something that Mr. P had done. What came to mind for him was that the goals each student pursued would be individualized and that he would want to talk with students one-on-one about their goals in science. This was a nice idea about supporting students to set individual learning goals for themselves, but was different from the epistemic aims Mr. P has described previously. These comments suggested that pursing epistemic aims and helping students understand the epistemic nature of science may not have aligned with the goals he thought were important for his students to adopt for their own learning in science. Alternatively, it is also probable that Mr. P simply had not reflected on this before and had not made that connection yet.

**Summary.** In summary, asking questions, solving problems and answering questions, and evaluating information reflected epistemic aims of developing knowledge and understanding that the teachers wanted to focus on in their classrooms. We saw similarities in the teachers’ strong value of students learning the larger epistemic aims of scientific practice, and we also saw some differences in what aspects of the aims teachers emphasized. While all three teachers wanted to focus on students pursing epistemic aims in their classes, Mr. C stood out as having developed a vision for his students to knowingly adopt and pursue epistemic aims in science. In contrast, Mrs. S and Mr. P had more unclear pictures of how to help align students’ mindsets
with pursuing epistemic aims. Teachers may want students to pursue epistemic aims in science, but they may not think about students taking up this understanding.

**Helping Students Understand *Why* Aspects of Scientific Practice are Important**

Next, we investigated whether and how teachers helped their students understand *why* to pursue epistemic aims in science. With supporting students’ metacognitive understanding about epistemic practice in mind, we were interested in how teachers helped students understand the purpose of what they were doing in the classroom and why these things were important in the practice of science. All three teachers described helping students understand why by having open and direct conversations with students about the goals they had for students’ learning in science, that is, the overarching goals for pursuing epistemic aims. However, when it came to day-to-day discussions with students about what they were doing and why it was important, Mr. C seemed to more explicitly discuss the purpose and importance of specific activities with his students than Mrs. S and Mr. P, who both saw the importance of some science activities as implicit.

It was evident from teachers’ explanations about their goals for students’ learning in science that they believed it was key to openly discuss these goals with their students and why these goals were important in science. All three teachers thought it was necessary to have specific conversations with students about wanting students to learn how to solve problems and think critically about information in science. We saw this clearly with Mr. C. as he repeatedly emphasized the importance of talking with students about why they were doing what they were doing. He described being very explicit with his students about why they were doing the activities they were doing in his classroom and how the processes they engaged in were important in science. He said:
Mr. C: They need to know why we are doing something. You know, yeah we can write the objective on the board, but if we are not talking back and forth about it, they are not going to get it…So it is all just frequent reminders, and here is where we are at. Here is what we are doing and here is why we are doing it.

This idea was present throughout Mr. C’s comments and was reiterated when he talked about how he helped his students adopt a problem-solving mindset from themselves by always returning to the bigger picture of what they were doing and why.

Mr. C also felt strongly that students needed to understand why particular criteria and processes were important in science and how they were related to each other. For example, he saw questions as central to science and made an effort to help his student understand their importance in science. Towards the beginning of the year, he would have a lot of discussions with students about “that’s what scientists do. They ask questions. So let’s figure out how to ask questions.” He thought it was important to start with this idea that science is about asking questions so that he could “always come back to that foundation of ‘this is what we do in science. This is why we are doing it’” with his students. Mr. C purposefully laid this foundation early on so he could help students see that asking and answer questions was central to science. He emphasized that asking questions was an integral step in the pursuit of developing and supporting claims with evidence. When asked how he helped students understand why the criteria for productive scientific questions they discussed in class were important, he said that these criteria were essential for asking the questions that would lead to evidence and reasoning needed to make claims in science. After describing that claims were based on evidence, he said:

Mr. C: Even before we make a claim, what questions do we have that lead us to it? So we might have all of these questions that lead us to this claim, but then we have to give that
evidence and reasoning behind it. And that’s why we need to ask those ‘phat’ [pretty hard and tough] questions.

As he describe why asking good questions was important, Mr. C emphasized that these were ideas that he purposefully discussed with his students.

Mr. C described similarly purposeful discussions that he had with students about the importance and purpose of criteria for conducting an investigation (e.g., identifying and controlling variables, carefully following a procedure). He said that he talked with students about the importance of setting up an investigation for reliability and replication, and that it was important for students to understand that scientific investigations are peer reviewed and what that means. Additionally, when students were analyzing data, he would discuss that the purpose of analyzing data was to solve the problem they were investigating. He tried to help students understand the importance of analyzing data by making the problem or question relevant to students, so students would take ownership of the problem and see why they needed to analyze their data. This idea of making problems relevant to students also came up in how he thought about helping students understand the purpose and importance of constructing explanations in science:

Author: How do you help your students understand why constructing explanations is an important part of science?

Mr. C: I think it goes back to that scientific literacy that we were talking about. And tying it into that.

Author: In what way would you do that?...

Mr. C: So, I guess the biggest thing would be explaining to them, or showing them or letting them develop their own, I don’t want to say, thoughts…well, I guess their own
reasoning as to why this evidence is important. What is all of this stuff going to tell you? And how is it going to help you, or help you make decisions? So, if they have learned how to look at all of this evidence critically, if they’ve learned how to, um, provide reasoning for a claim that they are making, how is that going to help them in life, I guess. When they are having issues with water quality in their house, or cars not working, or those types of things that are more general and relevant to people. Other than a specific scientific topic. Taking a look at those real types of issues.

From this except, it was clear that Mr. C thought pursuing questions or problems that students were interested in and saw as relevant to their lives was an important strategy in helping students understand why particular aspects of scientific practice were important. If students cared about the problem they were solving, they would see the relevance and purpose of analyzing data and constructing a well-supported explanation. It also appeared from Mr. C’s responses that he had thought about these ideas before and was intentional in his teaching to help students come to this understanding.

Similar to Mr. C, Mr. P described examples of having purposeful discussions with his students about the larger epistemic aims he had for their learning in science. Mr. P had emphasized wanting students to learn how to learn, and he described that he openly talked with students about this and explicitly told students that he was not going give them answers. Rather than answering students’ questions, he would respond with his own questions to guide their thinking, recruit help from other students, and give students time to think and figure things out on their own. He said this:

Mr. P: Early on, I tell them, “If you’re looking for me to give you an answer, it’s not likely to happen.” So I try to coach them how to ask questions. Or I will continuously
prod at them to figure out what it is. “So, why do you think that is?” It’s those questions where I am constantly trying to get them to think…As the year goes on, they start laughing at themselves. They’ll ask a question knowing, they’ll start giggling because they know I’m not going to give them the answer.

This excerpt showed how Mr. P expressed that openly talking with his students at the beginning of the school year about why he was not answering their questions was an important part of developing the expectation and understanding that students needed to work through their questions and find answer on their own or with other students.

Overall, we found similarities in teachers’ belief that they needed to directly talk with students about the big picture goals they had for students to pursue epistemic aims in science. But where the teachers differed was in talking about the purpose of specific activities and why certain criteria or processes were important to the practice of science. In particular, we noticed a difference in how the teachers perceived their own intentionality to help students understand the importance of activities they were doing in their classrooms. While Mr. C said that he had direct conversations about the importance of activities and aspects of scientific practice regularly with his students (as illustrated above), Mr. P and Mrs. S expressed that they had these discussions sometime but were not always explicit and purposeful in doing so. Mr. P and Mrs. S both described having conversations with students about the purpose of the activities they were doing. Most often, they discussed the importance of a process or activity in relation to the questions students were trying to answer, asking questions like, “What are you trying to figure out?” Mrs. S described that when her students were frustrated and wanted to know why they were doing something, she would often take this opportunity to have more extended discussions, turning the question back to them and asking them to come up with a reason for why.
But at the same time, Mr. P and Mrs. S both felt that the purpose or importance was often embedded or implicit in the classroom activity. For instance, when we asked Mrs. S how she would talk with students about why constructing explanations for important in science, she said, “We just kind of, we just do it. So I guess I don't say, ‘Oh it’s important. You have to do it.’ We just always do it. Maybe I’m not very explicit about it.” She continued to describe that she felt the prevalence of constructing explanations in her classroom, whether written or in discussions, conveyed its importance. Coming up with explanations was usually the culminating part of the investigations or activities they did in class, but she did not say to students, “this is important to do.” She talked about explanations leading to the next question, activity, or investigation, but it seemed that she did not purposefully talk about this with students. Similarly, Mr. P said that he did not purposefully talk with students about why asking questions was important in science. He responded, “I don’t know that I deliberately do that. I think it just kind of happens.” He described that rather than purposefully planning to talk about the importance, he might talk about this when the idea presented itself in the conversation. Mr. P thought that he was able to convey why asking questions was a central aspect of scientific practice, but this was not necessarily something that he intentionally set out to do.

**Summary.** In this section, our focus has been on how teachers supported students to understand why they were pursing certain goals in their science class and why the activities they were doing were important to the epistemic practice of science. Mr. C, Mr. P, and Mrs. S all thought it was important to explicitly and directly talk with students about what they wanted students to learn and understand about science (e.g., to solve problems, think critically, evaluate information, ask questions). But we found differences in how intentional teachers were about discussing the importance of specific activities. This difference stemmed from Mrs. S and Mr.
P’s views that the importance of some activities was obvious, implicit, or embedded in the activity. Teachers may not have seen a need to explain the rationale behind the specific aspects of scientific practice.

**Helping Students Understand How to Participate in the Epistemic Practice of Science**

So far, we have presented how teachers conceptualized *what* aspects of scientific practice were important for students to learn, and *why* these were important. Now we look at how teachers thought about and discussed helping their students understand *how* to successfully participate in scientific practice to achieve epistemic aims. We were interested in teachers’ thoughts about what epistemic ideals (criteria) and processes students needed to learn in order to successfully participate and how teachers could effectively support students to learn these. We asked the teachers what processes or skills they thought were important for students to learn in order to develop their scientific knowledge, and we then asked more specific questions about how they tried to help students participate in those aspects of scientific practice. We found similarities in the epistemic ideals and processes that teachers mentioned, although Mr. C stood out as having a noticeably connected understanding of how these ideals and processes were used to achieve epistemic aims in science. We also found that teachers shared common strategies for helping students understand how to participate in the practice of science, but that these strategies were used differently for particular aspects of science.

**Knowledge of epistemic ideals and processes for students to learn.** The teachers seemed to have a good understanding of the epistemic ideals and processes or skills they thought were important for students to learn in order to participate in the epistemic practice of science. They described students needing to ask questions, use and understand models, plan investigations or specific trials of experiments to answer questions, collect and analyze data,
understand how data from an investigation related to evidence for a particular claim, and continue to develop new questions. These processes that the teachers emphasized aligned with epistemic processes valued by the scientific community. One notable aspect of the teachers’ responses was the concise and connected way that Mr. C talked about these processes. He said:

Mr. C: Obviously, because of science, there is a big emphasis on collecting and analyzing data. There is that understanding that models are more than a physical model and how they can use those to solve problems. How do they, like I said, how do they plan an investigation. Not follow one, but plan it from the very start. What is their question? A lot of emphasis on questioning and asking the right questions and asking questions that will lead you to other questions.

Mr. C was able to clearly express these processes that he thought were important. Later when we transitioned from talking about asking questions to how Mr. C helped students learn to set up and conduct their investigations, he made a very clear connection between asking questions and conducting investigations. He responded,

Mr. C: Perfect question. Because we just got done talking about, right, that’s the lead up. The questioning is all the lead up. Questioning is the lead up to making a claim. And then how are you going to develop evidence that either supports or refutes that claim? So then we get into experimental design.

It was clear from this statement that he saw a strong link from asking questions to conducting an experiment and to developing evidence and claims.

Our follow-up questions about asking questions, conducting investigations, analyzing and interpreting data, and using evidence revealed that the teachers also understood standards for successful participation in these aspects of scientific practice that aligned with those of the
scientific community. All three teachers mentioned epistemic ideals for asking questions that included asking investigable or testable questions, deep “how” and “why” instead of surface level “yes” or “no” questions. The teachers also described criteria for purposefully planning and controlling variables in an investigation to answer a specific question, looking for patterns and relationships when analyzing data, and including evidence to support and convince others of claims or explanations. In describing how they would help their students learn how to participate in aspects of scientific practice, Mr. C, Mrs. S, and Mr. P all described variations of these criteria, exhibiting their knowledge of the epistemic ideals of science. While we expected teachers to understand many of the valued epistemic processes and ideals of science, we were especially interested in how they thought about teaching these in their classrooms.

**Approaches to teaching students how to participate.** The teachers discussed several predominant common strategies that they used to support their students’ participation in aspects of scientific practice. Asking guiding questions and having class discussions were two strategies that came up frequently. They talked about asking a lot of guiding questions in the moment to facilitate students’ thinking and push them in certain directions without giving them answers. Mr. C even described purposefully developing sets of questions that he planned to ask students to get them thinking critically. For having class discussions, the teachers described talking with the class about criteria for successfully participation in certain aspects of science, modeling how to meet these criteria, and using discussions to see what students were thinking. Mrs. S in particular repeatedly mentioned having class discussions as a main way she helped her students learn how to participate in science. The teachers also seemed to draw on different strategies for supporting different aspects of scientific practice. Next, we present the main strategies that teachers
discussed for helping students understand how to ask questions, conduct investigations, analyze data, and construct explanations.

*Asking questions.* Mr. C, Mrs. S, and Mr. P took similar approaches to helping students understand how to ask productive questions in science. They predominately described discussing the criteria of good scientific questions (described above) with students and modeling these types of questions. Of all the aspects of scientific practice we discussed with teachers, they felt that students had the most background knowledge by 8th grade about how to ask questions in science. They would discuss this criteria and examples of productive questions. Mr. C even saw the questions that he asked his students as a way to model the types of questions he wanted students to ask.

*Conducting investigations.* To support students to successfully conduct investigations, the first key thing that teachers described was helping them understand the question they were trying to answer. Again, the teachers mentioned discussing criteria for experimentation (such as controlling variables and purposefully conducting trials, mentioned above) and modeling how they might make decisions about setting up an experiment and manipulating variables. Mr. P and Mrs. S also brought up the importance of letting students make mistakes. They both wanted students to know that it was ok to be wrong in science and for experiments to fail – giving students opportunities to reflect on what went wrong in their investigations was a valuable way for them to learn. Mrs. S in particular emphasized this idea. Recounting a recent experiment that students did in her classroom she said, “They failed a little bit, and that was ok. We talked about that, you know ‘you made that mistake and that’s ok, but what did you learn from it? What would you do next time?’” While she thought it was important to talk with students in advance about how to control and manipulate variables to answer a particular question in an experiment,
she also thought that allowing students to make mistakes in how they conducted an investigation, recognize the consequence of those mistake, and reflect on what to do differently was a powerful strategy.

*Analyzing data.* Asking guiding questions came up throughout our discussions with the teachers but was a particularly salient strategy that teachers used when helping students learn to analyze data. Mrs. S and Mr. P both mentioned that analyzing and making inferences from data was challenging for students, so they were always asking a lot of guiding questions to support students’ sense making. All of the teachers gave examples of the types of questions they would ask students to help them find and understand patterns in their data, such as, “What are the trends? What do you see? What do you think this means?” Mr. C gave the following example from a recent population genetics activity he did with students that illustrated his approach to asking questions that pushed students beyond surface level relationships to understand the meaning of their data:

Mr. C: They had all of this data at the end of, all of this population data of what happened as they went through different scenarios. So then it was a matter of, “ok kids, let’s sit down, we’ve got all of these numbers here, where do we put them? How do we organize them? What does it tell us?” Throwing that question out there. “Well, it tells us that some monkeys died.” “Well, yeah it did tell us that some monkeys died, but big picture, what’s it really telling us? Why did those monkeys die?” So then you start with the questioning and getting that.

Author: So how do you help them make those kinds of connections?

Mr. C: Just questions. Lots of questions, questions, questions.
Here, Mr. C described asking many guiding questions to help his students make connections and see the relationship between different pieces of data in order to reason about what happened in their investigation. All three teachers expressed that their students did not really know what questions to ask about their data in order to make sense of it, so the teachers relied on asking guiding questions to help model the thought processes needed to analyze data.

*Constructing explanations.* The teachers seemed to provide the most concrete structure to help students construct explanations, compared to other aspects of scientific practice. They all had particular models, frameworks, or sentence stems that they used for writing explanations. Teachers typically taught these structures to students at the beginning of the school year and then continued to use them throughout the year. Mr. C described his use of a “claim, evidence, reasoning” model that he would teach at the beginning of the year and then continually revisit throughout the year. He used graphic organizers to help students understand what to include in an explanation and to show where they were in the claim, evidence, reasoning model at different points in time. Mr. C also talked about using a lot of examples and scenarios to help student understand how to use evidence. He gave an illustrative example of trying to figure out why his car would not start by going through the available evidence asking questions like, “what evidence do I have, what does that tell me?” For instance, if the lights turn on, that is evidence that the battery works. Mr. P described the framework for writing a scientific report that he used with students, and Mrs. S gave examples of sentence stems (e.g., “I know this because” or “My hypothesis was correct because”) that she used in her classroom. Mrs. S described that she was often very explicit with her students about what to include in their explanations. Having experiences teaching both 6th and 8th grade, she described that she provided a lot of structure for both age groups, but felt that she probably provided less structure over time with the 8th graders.
Each teacher appeared to have a clear vision of the criteria they were looking for in students’ explanations and a structure for how to meet these criteria that they taught students.

**Summary.** Mr. C, Mrs. S and Mr. P all seemed to have knowledge about the epistemic ideals and processes used in science and how these were employed to achieve epistemic aims. When it came to explaining how they helped their students understand how to participate in the epistemic practice of science, we noticed the teachers relying more heavily on different strategies for particular aspects of science. Discussing epistemic ideals or criteria with students was used heavily to help students ask productive questions, opportunities to try and learn from mistakes seemed important in learning to conduct investigations, asking guiding questions was essential for helping students analyze their data, and providing explicit frameworks or structures was used to help students understand how to use evidence to construct explanations.

**Teachers’ Reflections on Their Own Teaching**

Teachers discussed their approaches to teaching during the interviews and then watched videos of themselves to reflect more on their teaching. Our goal in showing these videos was to prompt deeper and contextualized reflection to better understand teachers’ approaches to teaching science as epistemic practice. In this section, we present differences we found in teachers’ confidence in their instruction and the insights teachers had about their own instruction as watched and reflected on the videos.

**Teachers’ confidence in their instruction.** As teachers reflected throughout the interview, we saw a noticeable difference emerge in the confidence with which Mr. C, Mr. P, and Mrs. S described their approaches to teaching science. Mr. C and Mr. P both expressed that they felt very comfortable thinking and making decisions in the moment and “going with the flow” in their classrooms. Mr. C seemed quite self-aware with respect to his teaching. He
described himself as reflective, felt experienced and knowledgeable in his classroom, and was confident in his ability to develop the right questions to ask his students. He clearly expressed this confidence when he said, “I like to think that I am pretty quick on the fly and can engage kids through questioning that is thought provoking as we move through a lesson.” We also saw his confidence in his approaches to teaching through the ways he quickly and directly gave thoughtful answers and explained his views of teaching throughout the interview. Mr. P also talked about his ability to comfortably think on his feet and how this influenced his teaching style. Rather than having a predetermined “game plan,” he preferred to adapt his instruction to the individual students in a given situation. When talking about how he helped students make connections between their data and how that data could be used as evidence to support a claims, he said:

Mr. P: Each case is so different. I try to feel where the kid is going and I try to help get them to where we want to go. Every instance, it just depends. For me it’s more of a feel game. I don't really know, I don’t really go into it with any game plan. I just want to see what is happening with each individual or group.

Mr. P expressed a desire to build off of the current situation by listening and adapting to his students. He brought up this idea again when he described how he modeled writing productive scientific questions in the context or flow of class rather than as instruction before an question writing activity.

Mr. P: My teaching style tends to be just a go with the flow. Where is the class going, and try to work with them. So that way there is kind of a feel that we can all be comfortable with in the class.
Mr. P felt confident in his “go with the flow” approach and felt that it worked well for him, though he acknowledged instances where maybe he “could” or “should” take different approaches. For instance, when we asked him how he helped students understand why questions were important in science (discussed previously), he expressed that he did not think this was something he purposefully discussed with students but maybe he should. Mr. P felt that his approach worked well for him but also acknowledged that planning some of these types of discussions might be beneficial too.

In contrast, Mrs. S expressed some doubt about her approaches to supporting students understanding and participation in the practice of science and admitted that sometimes she was not sure what else she could do to help her students. Throughout our discussion, she ended many statements with “I don’t know,” and “Does that make sense?” It was not clear whether these comments reflected that she truly felt unsure about her own teaching or whether she was struggling to express her thoughts – she alluded to the later possibility when she mentioned needing time to process her thoughts and that she would probably think of many things she wished she had said later. Beyond these comments that expressed some uncertainty, there were several instances in which she openly stated that she was not sure how to help her students or what other strategies she could use beyond what she was currently doing to support her students. For example, when we asked how she helped students understand how to write productive questions in science, she responded, “That’s something that I still work on.” She mentioned several times that she thought this was an area in which she could improve, especially in helping students understand why some questions were more productive than others. Additionally, when Mrs. S talked about helping students analyze data and construct explanations, both of which were
challenging for her students, she said that sometimes she was just not sure what else she could do to help them. For analyzing data, she said:

Mr. S: You know sometimes I’m like, “How do I help them analyze it?” You know, other than giving them opportunities, other than walking them through it, other than having that discussion and asking those questions, how can I help them to analyze the data? So that’s, I don’t know.

Here, it seemed that she was actively wondering and thinking about other ways that she could support her students to understand this challenging process. Similarly, when talking about constructing explanations, she said, “I’ll be honest, some days I’m like, ‘other than telling you the answer, I don’t know. I’m not going to give you the answer.’” In these examples, Mrs. S openly expressed that she was not always sure how to help students successfully participate in scientific practice when they were struggling. Analyzing data and using evidence to construct explanations seemed to be the aspects of scientific practice that were the most challenging for students, and Mrs. S struggled to find ways to help her students overcome these challenges. She had strategies that she used, but when these were not working, she was not sure what else she could do.

Teachers’ reflections on videos of their own teaching. We asked teachers to reflect on a couple of video clips of themselves teaching the compost curriculum described previously. We asked them what they noticed about their teaching in the videos, how they were trying to support students’ learning, what they liked about their instruction, and what they might do differently in a similar situation. In this section, we present several insights that teachers had about their teaching from this reflection.
Mrs. S. The most interesting insight came from Mrs. S. We showed her a video of her asking students why they thought they were writing research questions about how biotic and abiotic factors influence decomposition. In the video, she asked students, “Why are we doing this? Why are we writing these questions? Why are we doing this research?” and had students share their ideas with the class. We had selected this video as a nice example of how she tried to help students understand the purpose of the activity they were doing and how writing research questions was connected to their larger goal of developing a successful compost, and we had interpreted her intentions as such. However, it was not clear to Mrs. S what her goals were in the episode. After watching the video, she expressed that she was not sure what she was trying to accomplish. She said:

Mrs. S: I don’t even know. Looking at this, I feel like that was very unproductive. So I think sometimes, what I have in my head and how I go about doing things, I’m like, they didn’t get anything out of this did they? You know what I’m saying?

Author: Why do you think it was unproductive?

Mrs. S: I don’t know. Looking at it, they are just, it looks like they are just, and maybe I don’t remember what it was. But they are just giving me very basic, “Why are we doing this research?” “Well to compost.” You know like, it just seems very superficial. Is that what I was going for? I don’t even remember.

Mrs. S seemed confused by her intentions in this episode because she was not sure what this discussion had accomplished with her students. What Mrs. S saw in the video was a superficial discussion about the purpose of the activity. Retrospectively, she struggled to understand why she might have thought this was a productive conversation at the time. She expressed in her reflection that what she really wanted to do was to help her students understand the larger
purpose and goal of the unit, why it was important and relevant. She expressed disappointment that none of her students talked about this bigger picture goal of what they were doing and how the purpose of writing research questions and conducting research was connected to explaining how to create a successful compost. While we saw her actions as taking a step towards helping her students understand the purpose of what they were doing, Mrs. S did not see the deeper responses she was looking for upon reflection. In the video, she seemed satisfied with students’ responses in the moment, but upon reflection, she took a more critical view and was left wanting deeper reasoning from her students. It is possible that Mrs. S did not have enough context about what had been happening previously in the class to interpret her intentions in this video. However, there was still a difference in what she expected to see in the video based on her own goals for students’ learning and what she saw that sparked questions about whether the intentions she had were coming across in her teaching. She reflected more on this idea at the end of the interview. She said:

Mrs. S: But you know like even just having that conversation and then looking at the video, it was almost like, what I have in my mind, is it really getting out? Am I really doing what my intentions are? Is it really coming across that way? And that’s something for me to be more aware of… I feel like in my brain there is a disconnect between what I want them to learn and what they are actually maybe doing.

In this excerpt, we witnessed the culmination of Mrs. S’s reflection, in which we realized that there might be a disconnect between her intentions and her actions. She expressed that our discussion during the interview and the opportunity to watch videos of herself prompted this realization. In particular, it seemed that her struggle to understand her intentions by watching and reflecting on her actions prompted her feelings of discontinuity. While the interview created
space for her reflection, Mrs. S raised these ideas and came to this realization on her own. Her reflection here seemed to correspond to some of the uncertainties she had raised previously about how to help her students understand and participate in science as epistemic practice.

**Mr. P.** As Mr. P reflected on the videos of his teaching, he was able to quickly identify the goals of his instruction and pointed out strategies that aligned with those he had discussed using previously in the interview. Overall, he saw ways that his instruction supported students to participate in important aspects of scientific practice, but he also noticed adjustments he could make to improve and maximize the benefits of this support. For example, in one of the videos, Mr. P identified that he was trying to help students analyze the data they had collected from experiments and use that data as evidence to support their about why the temperature in their compost was increasing, rather than relying on their “anecdotal evidence.” He said that students kept wanting to go back to “what they believed was going to happen” instead of looking at their data. He noticed the way that he continued asking students questions, he liked the specific questions that he asked, and he thought that he was doing the “right thing” by driving students back to their data. We had identified these same features of his teaching when we selected this video to show Mr. P, something that we noticed he did frequently in many class periods. But what stood out to Mr. P the most about his teaching was the amount of time that he gave students to think and answer the questions he asked. He thought he had done a nice job of asking guiding questions, but he felt that he did not give students enough time to think about these questions. He said:

Mr. P: I think I was doing the right thing in driving them back to their data, but I think I needed to give them more time to talk amongst themselves about what the data was actually showing them. I think I was doing a pretty good job of trying to keep on pushing
the idea of the data, and trying to get them to explain why the data was so important…

But I think I was too impatient with their ability to do it that I just kept on driving and asking more questions and maybe I should have backed off a little bit and let them think for a little bit without speaking.

As he continued reflecting, he felt confident that giving students more time to think and discuss their ideas with each other would have helped achieve his goal of helping students analyze and reason from their data. Through this reflection, Mr. P identified the strategy of asking guiding questions that he had discussed as a prominent way he supported students earlier in the interview, but he was also able to identify a way that he would alter this strategy to better help his students understand their data.

**Mr. C.** Similar to Mr. P, Mr. C easily identified his intentions in the videos we showed him. In the first video, he recognized that he was helping students understand how they were going to conduct a virtual experiment to investigate how moisture affected decomposition in a compost. More importantly, Mr. C identified that he was trying to help students understand that conducting the experiment was not just about collecting data and writing down the numbers, but about understanding what they were going to do with the data and how it was going to help them answer their questions. He described:

Mr. C: I said it somewhere in there, it’s not about the data. So we are going to get the data, but it’s about, “How are we going to use this? What are we going to do with it? How is it going to lead us to answer these questions?”

He reiterated that he wanted his students to understand the bigger picture and purpose of what they were doing in the experiment. He highlighted the importance of two reflection questions that were embedded after each trial in students’ data tables and emphasized that he had directed
students’ attention to these questions to encourage them to be reflective and purposeful in their experimentation. He said:

Mr. C: It’s not just about getting numbers. It’s about answering those two very relevant questions that will allow them to build in their next experiment, or their next trial…We are showing them that we have collected this, we have got these numbers now when you ran your moisture trial, and these questions are looking at those numbers and reflecting on them. How are they going to help you build for that next trial?

The ideas that Mr. C expressed here about recognizing the larger purpose rather than focusing on simply writing down information aligned with his desire to change students’ mindset about “doing school,” which we discuss in the next section. He recalled that students often wanted to get through the trials of their experiments quickly without thinking about what was happening. He emphasized with his students not to rush and skip the reflection questions and would tell them, “This is not thinking critically, this is not rationalizing what we are going to do next. You have to have some reasoning as to why you are doing the next thing.” Here, we again saw evidence that Mr. C was intentional about having direct conversations with his students about expectations for thinking critically, providing reasoning, and focusing on the problem they were trying to solve versus simply finishing an activity. In reflecting on what he might do differently, there were several times in the videos where he felt that there was a lot of “teacher talk” and silence from his students after he had asked the class a question. Like Mr. P, Mr. C thought he was asking good questions and liked the way he was trying to guide students’ thinking. Mr. C created a lot of space for students to respond by waiting and being comfortable with the silence, but he felt that he could have improved the situation by asking students to talk to a neighbor or their group when no one was responding. Based on his experience, Mr. C believed that this
would have been quite helpful for moving the conversation forward. This insight was similar to Mr. P’s in that Mr. C noticed positive instructional moves he was making but also recognized an adjustment he could have made to improve the situation and reach the student discourse that he desired.

**Summary.** Teachers’ reflections on their own teaching revealed insights into their confidence in their approaches to teaching science and awareness of how their intentions were being enacted. Mr. C and Mr. P expressed confidence in their instruction. They both also identified their intentions in the videos and, for the most part, liked the instructional moves they were making. They identified many of the same ideas that we had noticed in the videos, echoed strategies they had discussed previously in the interview, and provided some additional information about their decision making which showed that they were aware of and purposeful in their actions. They thought that they were asking productive questions that would guide students in a desired direction, but reflection allowed them to recognize some changes they could make to either give students more time to think or collaborate with their peers to process their ideas. On the other hand, Mrs. S expressed some uncertainty in her approaches to teaching scientific practice, not knowing what else she could do when her strategies were not working. We also had a revelation that her intentions may not have been manifested in her actions. When she was confused and unable to make sense of what she had been trying to accomplish in a discussion with her students, she questioned whether she was doing what she intended to, and she wanted to reflect more on ways she could assess how her students perceived the purpose of her actions.

A final observation that came from the video reflection portion of the interviews was that all of the teachers expressed that reflecting and watching the videos of themselves was a valuable experience. Mrs. S, Mr. P and Mr. C all mentioned that they noticed things about their teaching
in the videos that they had not realized before. There was a common recognition across the
teachers that they were likely their “own worst critics” (a phrased used by Mr. P and Mr. C), but
that their criticality stemmed from their desire to improve. Mr. P expressed this idea most
clearly:

Mr. P: You know I think we are always our own worst critics. And instead of looking for
the positive, often times I’m looking, for me personally I always want to know how I can
improve. It’s really easy to see the things you are doing right, and I think I was doing a
lot of things right in there. But at the same time, how could I have done it better?

The teachers felt that being able to see and reflect on their teaching was beneficial, and they
freely volunteered that it was an enjoyable and useful experience. While we as researchers
believed that reflection would be useful, these comments revealed that the teachers genuinely
found reflection to be useful and productive for learning about their own teaching.

**Challenges to Teaching Science as Epistemic Practice**

The teachers raised some significant challenges to teaching science as epistemic practice
in their classrooms. One major challenge was that students were often resistant to the epistemic
aims that the teachers wanted to pursue in their classrooms. The teachers wanted students to be
curious and learn how to ask questions, investigate their questions, provide evidence to support
their answers, and evaluate information and others’ claims. However, they knew that this was
often not what students wanted or had been prepared to do. Mr. C explained this most clearly
when he described that the biggest obstacle he faced in helping students understand science as a
process of evaluating and developing explanations was “changing the mindsets of kids.” He
elaborated:
Mr. C: They’re, I use this term, I think it’s going to be the title of a book someday. Kids have been “schoolified.” You know, they have been taught, they sit in class, they get the information, they take a test, they move on to something else. They haven’t necessarily been taught how to think through and work through problems, and problem solving and making those connections on their own. And that’s hard for them. And especially in middle school, they balk at that right now. I think it’s changing a little bit.”

He was very open with his students about these thoughts as well. He would use the term “schoolified” with them and tell them, “you guys have been taught to sit and get information and then puke it back out to us, regurgitate it back out. And that’s not education, that’s not learning.” But he was also open with his students about how difficult making this change was: “We talk about how difficult this shift is. But it’s a critical shift we need to make.” It appeared that Mr. C’s approach to overcoming the challenge of changing students’ mindsets about school was to openly discuss this challenge and why it was important to address with his students.

Related to students’ “schoolified” mindset, the teachers raised the challenge of students’ engagement and interest. All three teachers discussed struggling with students being apathetic and uninterested. Mr. P said that some students became apathetic and did not care about what was happening in the classroom, and he felt that he had to work hard to give them a reason to care. Similarly, Mrs. S described students’ lack of participation and interest as a struggle to getting them to ask questions and construct explanations. For example, when talking about helping students understand why using evidence was important for constructing explanations she said, “I think they know why. They don't want to do it.” Mr. P and Mr. C also described that students were use to getting answers immediately and did not want to put in effort or think deeply to understand what was happening. Asking surface level questions was easier than
digging for harder “how” and “why” questions, and taking the time to analyze and truly understand data required time and effort that students did not want to give.

The other key challenge that teachers faced in teaching science as practice in their classrooms was time. Mr. P and Mr. C talked about time constraints significantly influencing the learning opportunities they were able to create for students. Mr. P, for example, wished that he was able to have students conduct more in-depth investigations, but felt that there was not enough class-time to devote to this while covering all of the material he was held accountable to teach. He also mentioned time constraints with respect to his own time: he wanted to develop larger investigations that would give students opportunities to engage in more authentic scientific practice, but he felt that he did not have the time or resources to do this during the school year. Similarly, Mr. C cited time as a big challenge. He describe that teaching science in a way that focused on science as practice took time: “You know, because this type of thinking and this type of education is time consuming.” In particular, he talked about time being an issue for wanting to conduct investigations in class and helping students learn how to successfully use evidence and construct explanations.

In sum, students’ resistance to deeper and more effortful understanding and not having enough time to engage students in extended investigations were constant challenges that the teachers faced in supporting students to learn the authentic practice of science. These were practical challenges that the teachers felt on a day-to-day basis that were, in some ways, out of their control. Students’ willingness and motivation to engage in meaningful learning and actually having time to do the activities that teachers thought would help students participate in the authentic practice of science were both barriers to creating communities of scientific practice in classrooms that teachers had not yet figured out how to overcome.
Discussion

Teachers’ epistemic cognition plays a key role in their teaching and the learning environments they create for their students (Bråten et al., 2017; Buehl & Fives, 2016; Lunn Brownlee et al., 2017). Understanding how teachers think about the epistemic practice of science is an important step in supporting teachers to create communities of scientific practice in their classrooms. Our goal in this paper was to better understand how teachers conceptualized teaching science as epistemic practice, specifically the epistemic aims they wanted students to pursue and the ways in which they tried to support students to understand and participate in the practice of science. Our main findings were as follows:

1. Asking the teachers what they most wanted their students to learn in science revealed that all three teachers desired a focus in their classrooms on epistemic aims of how to develop knowledge and understanding in science, although they emphasized slightly different conceptualizations of these aims. This desired focus on epistemic aims, however, did not necessarily align with the aims that Mrs. S and Mr. P said they hoped their students had for their own learning.

2. We found differences in the intention with which the teachers helped students understand why activities they were doing were important to scientific practice. Mr. C was especially deliberate about talking with students about the purpose of activities and the importance of particular ideals.

3. All three teachers had knowledge of the epistemic ideals and processes used to develop explanations and understanding in science. They employed similar strategies to help students understand how to participate in the epistemic practice of science, but these strategies differed based on the aspects of practice.
4. In reflecting on their approaches to teaching, Mr. C and Mr. P seemed more aware of and
confident in their support than Mrs. S. In watching their teaching, all three teachers
recognized aspects of their instruction that they wanted to improve. Mrs. S had the largest
realization – through reflection, she questioned whether her intentions were coming
across to her students in her instruction.

5. Teachers raised important challenges to teaching science as epistemic practice, including
students being apathetic, not wanting to engage in effortful learning, and wanting answers
quickly. The teachers also struggled with not having enough time to do the extended and
authentic investigations with students that they believed would be meaningful.

We discuss and synthesize these key findings with respect to three main ideas: (a) supporting
students’ epistemic aims in science – in which we make connections between findings one and
five, (b) teachers’ intention to help students understand why activities are important – finding
two, and (c) teachers’ understanding and reflection about their own teaching – in which we make
connections between findings three and four.

**Supporting Students’ Epistemic Aims in Science**

Understanding science as epistemic practice involves awareness about the epistemic aims
of science, and why and how various epistemic ideals and processes are in service of these aims
(Barzilai & Chinn, 2018). A key aspect of supporting students to learn the epistemic practice of
science is helping them develop this metacognitive level of epistemic thinking (Barzilai &
Chinn, 2018). In our study, teachers articulated similar ideas about wanting students to learn how
to pursue epistemic aims. Teachers conceptualized and expressed these epistemic aims in
different ways – focusing more on solving problems, thinking critically, evaluating information,
or understanding how theories are developed – but what was common across these
conceptualizations was the epistemic nature of scientific practice to understand the natural world. That teachers value the pursuit of epistemic aims in science is essential for students to learn science as epistemic practice, because teachers create the learning context for their students (Buehl & Fives, 2016). Knowing that teachers want their students to develop explanations, solve problems, and understand how knowledge and theories are constructed in science is valuable for efforts to support teachers to teach science as epistemic practice. Based on prior work that teachers’ epistemic cognition influences the learning opportunities they create for students, thus influencing students’ epistemic cognition (Bråten et al., 2017; Buehl & Fives, 2016; Muis & Foy, 2010; Ryu & Sandoval, 2012), teachers valuing and wanting students to pursue epistemic aims is a crucial precursor to students learning science as epistemic practice.

However, our study also showed that the epistemic aims that teachers wanted students to pursue did not necessarily match the aims that teachers thought about students adopting for their own learning. To foster communities of scientific practice in classrooms in which students are knowledgeably pursuing epistemic aims, it seems essential for students to adopt epistemic aims for their own learning in science. But when thinking about aims in science from the perspective of their students, Mrs. S and Mr. P described more practical, school-like goals. Wanting students to think critically, evaluate information, and pursue explanations and solutions to problems (the epistemic aims teachers said were most important for students to learn) is not the same as wanting to students to find science interesting, be open-minded, and try to learn something even when they do not want to (some of the aims teachers hoped students would adopt for their own learning). It is possible that these epistemic aims that teachers initially described and the aims they hoped students would adopt appeared misaligned because Mrs. S and Mr. P had not thought much about aims from their students’ perspectives. Perhaps they needed more time to reflect and
make the connection back to the epistemic aims they had expressed earlier. But this misalignment may also relate to the *challenges* teachers raised about students’ apathy, lack of interest, and the “schoolified” mindset. If teachers see their biggest challenge as overcoming students’ apathy and lack of interest, it may be most relevant or pressing to hope that their students adopt a willingness to try and develop an interest in science.

These findings speak to Buhel and Fives’s (2016) suggestion that teachers can have conflicting aims. In particular, these researchers describe that teachers may have non-epistemic aims that conflict with the epistemic aims that they want for their students. Dealing with the challenges of students apathy and time pressures may result in school-based aims that may be non-epistemic and compete with supporting epistemic aims that align with scientific practice. Just as teachers must coordinate many factors in their classrooms, they may have different, and possibly competing, aims for their students that they must prioritize in various situations. Teachers may have desires for their students to pursue epistemic aims, but in the day-to-day of science classrooms, they may not focus on helping students take up these epistemic aims, and non-epistemic aims may prevail.

The challenges teachers described raise further questions about the role of students’ interest and motivation in supporting epistemic practice in science classrooms. Aligning the epistemology of classroom communities with the epistemology of the scientific community hinges on pursuing epistemic aims (Berland et al., 2016), but can this happen if students are not motivated to pursue such aims? Probably not. Presumably, the scientific community is genuinely interested and motivated to build explanations about the natural world. To what extent does students’ successful participation in epistemic practice require such interest and motivation?
Further exploring these questions, both conceptually and empirically, may prove fruitful for better supporting teachers to foster communities of scientific practice.

**Teachers’ Intention to Help Students Understand Why Activities are Important**

Scholars have discussed, in various ways, the need for students to understand the rationale for why they are doing what they are doing and the epistemic nature of their actions (Barzilai & Chinn, 2018; Barzilai & Zohar, 2016; McNeill & Krajick, 2008; Sandoval, 2005). Helping students knowingly adopt and pursue epistemic aims in science requires helping them understand what they are doing and why it is important for scientific practice (Barzilai & Chinn, 2018; Barzilai & Zohar, 2016). Further, supporting students to understand the purpose and importance of what they are doing and to see their own efforts as constructing valued knowledge is thought to require direct and explicit guidance (Sandoval, 2005). Our findings highlighted important differences in the intentionality and the perceived need with which teachers discussed the purpose of activities with their students. While Mr. C expressed an intentional, purposeful focus on helping students understand why they were engaging in particular activities and why they needed to follow particular standards for successfully participating in scientific practice, Mrs. S and Mr. P were not as direct with their students. Mrs. S and Mr. P described discussing the importance of some aspects of scientific practice with students, but they viewed the importance of other aspects (like asking questions and constructing explanations) as implicit in the frequency of these activities in their classes. Whether they discussed the importance of particular activities or processes for scientific practice was not a matter of the teachers understanding this importance, but rather of thinking that the importance was obvious or embedded in the activity. If teachers are monitoring students’ understanding and recognize that students already know why an activity is important or the role it plays in the construction of
knowledge in science, then it might be beneficial for teachers to focus on other aspects of instruction given limited class time. However, prior work has shown that students often need help to understand the purpose and rationale of what they are doing in science (Sandoval, 2005), particularly when it comes to understanding how to construct explanations (McNeill & Krajick, 2008). Similarly, students may need sustained support and explicit guidance about the purpose and importance of what they are doing to truly understand science as epistemic practice.

Teachers intentionally helping students learn science as epistemic practice seems critical for shifting the focus in classrooms to the ways of building knowledge in science, and this is still lacking. In our prior work, presented in chapter 3, we found that while teachers talked with students in their classes about the epistemic aims of particular science activities and why these activities were important, this support was limited. In line with these classroom findings, the current study – with some of the same teachers – suggests that teachers may not be purposefully trying to enculturate students in the ways of building knowledge in science. Teachers seemed to understand the epistemic nature of science and valued that students learn to participate in scientific practice, but helping students understand how and why to pursue these aims was not necessarily a focus in their classrooms. Whether due to a lack of intention or the practical challenges of implementing a focus on practice in school contexts where content is often what is valued on tests, helping students understand the nature of the scientific enterprise is not yet central in science classrooms.

**Teachers’ Understanding about Their Own Teaching**

Teachers’ epistemic cognition about how knowledge and understanding are developed influence their approaches to teaching and the epistemic aims they pursue with their students (Bråten et al., 2017; Buhel & Fives, 2016; Lunn Brownlee et al., 2017). Our findings highlight
that teachers’ epistemic thinking about their teaching – that is, their awareness and monitoring of the goals they have for students’ understanding and participation in epistemic practice and how their instruction is supporting those goals – is another level of teachers’ thinking that may be crucial for supporting students’ learning. A key difference we found between the teachers in this study was their awareness and understanding of their own instruction. Mr. C and Mr. P were both confident in their instruction and their ability to adapt to students’ ideas. Mr. C was also particularly reflective and knowledgeable about his own approaches to teaching science, and he provided coherent responses to questions that suggested he had thought about teaching science as epistemic practice previously. Mrs. S, on the other hand, expressed more uncertainty in her approaches to teaching science as an epistemic practice and had an eye-opening realization during the interview that maybe her intentions were not coming across in her instruction. While Mrs. S exhibited knowledge of strategies she used to help her students understand how to participate in valued aspects of scientific practice, she was not sure what else she could do when those strategies were not working.

It may be that being reflective about their teaching and feeling comfortable adapting instruction in the moment helped Mr. C and Mr. P also feel more confident than Mrs. S about their approaches to teaching. Lack of confidence has been shown to be a challenge that influences teachers’ enactment of instruction (Elby et al., 2016), so this is an important issue to be aware of in considering how to support teachers. Teachers may have an understanding of the epistemic nature of science and may have knowledge about strategies to teach science as epistemic practice, but ensuring that teachers have confidence in their knowledge and ability to implement this instruction should not be overlooked. Alternatively, what we interpreted as Mrs. S not feeling confident could instead reflect an openness or willingness to question her teaching
that was actually beneficial and allowed Mrs. S to have an important realization about her teaching. More research could help tease apart these different interpretations and further investigate the relationship between teachers’ self-reflection or questioning and their confidence in their approaches to instruction.

Prior research has shown discrepancies between teachers’ intended and enacted instruction and beliefs (Elby et al., 2016). There are many individual and environmental factors at play in a classroom that can contribute to these discrepancies (Remillard, 2005; Stein et al., 2007). To minimize these discrepancies, it seems essential for teachers to be able to recognize and monitor their intentions behind particular classroom activities or instructional moves and whether these are translating into their practice. If teachers have intentions behind instructional moves that do not come across in their actions, then this instruction may not effectively support students’ learning. Teachers could have sophisticated understandings about the epistemology of science – wanting their students to pursue epistemic aims of developing scientific explanations and understanding how such aims are achieved in the scientific community – but if this understanding is not reflected in their instruction, students may not learn the epistemic practice of science. Such discrepancies are problematic, but a lack of awareness that teachers’ intentions are not being actualized may be even more problematic. In our study, Mrs. S provides an example of a teacher who had epistemic aims for students to develop explanations about the world, evaluate information, and understand valued epistemic ideals and processes of the epistemic practice of science, but she was not aware of how these ideas came across in her teaching. It was not until she saw and reflected on videos of her own teaching that she began to question whether her intentions were actually being enacted in her teaching. In a powerful moment, we witnessed Mrs. S recognize possible discrepancies in her own teaching.
As Bråten and colleagues (2017) have said, teachers likely need support to see inconsistencies in their intended and enacted instruction. The case of Mrs. S in our study supports these prior suggestions and the need for helping teachers become more metacognitive about their teaching. It was a big step for Mrs. S to recognize that her intentions may not be translating into her actions, but an essential next question is how we can then help teachers put their visions into action to overcome these discrepancies. Reflection has been shown to be a powerful mechanism for improving teachers epistemic cognition and instruction (Bråten et al., 2017; Lunn Brownlee et al., 2017) and may be particularly useful to help teachers think about how the aims they have for their students align with epistemic aims of the scientific community and how those aims are being enacted in their instruction.

Conclusions and Future Directions

Shifting the epistemology in science classrooms to align with the epistemology of the scientific community is necessary but challenging in the effort to help students learn the epistemic practice of science (Berland et al. 2016). Teachers are essential in creating learning environments for their students (Remillard, 2005; Stein et al., 2007), and more specifically, teachers’ conceptualizations of the construction of knowledge and understanding influence the learning environments they create (Bråten et al., 2017; Buehl & Fives, 2016; Lunn Brownlee et al., 2017; Tsai, 2006). Supporting teachers to understand the epistemic practice of science and to translate that understanding into instruction that fosters communities of scientific practice in their classrooms is an important step that cannot be overlooked. Our study showed that teachers may have knowledge about the epistemic aims of science and the epistemic ideals and processes used in science to pursue those aims; they may also have ideas for how to help their students understand these ideas and participate in scientific practice. But actually translating this
knowledge into instruction that helps students adopt these aims and participate in the epistemic practice of science may require much more than creating opportunities for students to pursue epistemic aims. More pressing and practical aims, intention to convey the epistemic importance of activities, confidence in their instruction, awareness of their own teaching, students’ interest and engagement, and time are critical factors that may influence teachers’ ability to successfully implement their knowledge of scientific practice. Our study offers an in-depth, qualitative account of how these internal and external factors might constrain the creation of desired epistemic environments in science classrooms and is a step forward in addressing the gap in understanding such constraints identified by Bråten and colleagues (2017). Further, we suggest that teachers’ ability to manage these factors may depend on their own awareness and understanding of the relationship between their intentions and their instruction.

Our findings highlight several key issues. First, unexplored nuances and possible misalignments in the epistemic aims that teachers wanted their students to pursue raise questions about whether some epistemic aims may be more productive, or interfere with each other, for teaching science as epistemic practice. While we have taken a step towards understanding the relationship between teachers’ approaches to instruction and the epistemic aims they want students to pursue in science, more in-depth and targeted investigations into the effects of particular epistemic aims on teachers’ instruction and the creation of communities of scientific practice would be beneficial. Second, it was clear from our study that a teacher wanting students to pursue epistemic aims does not result in students wanting to pursue epistemic aims. To create communities of scientific practice in classrooms, it will be important to understand how to support students to actively engage in the pursuit of scientific explanations and knowledge and how to make a focus on practice central in classrooms. More work is needed to investigate
factors that influence students’ adoption of the epistemic aims their teachers may desire. In particular, we see the intention and purpose with which teachers talk about the importance of aspects of scientific practice as a factor that may be especially important. As also noted by others, there is a need to better understand the development of epistemic aims and how to promote this development (Chinn & Sandoval, 2018; Sandoval, 2015).

Finally, our study sheds light on the importance of teachers’ understanding about the relationship between their intentions and their instruction and the role that reflection could play to support this understanding. Key differences in (a) teachers’ intention to help students understand why aspects of scientific practice are important and how their own efforts are part this epistemic practice and (b) teachers’ recognition of the intentions behind their instruction help to identify specific areas where reflection might be used to support teachers to teach science as epistemic practice. Given the importance of teachers’ epistemic cognition in creating environments for student learning (Bråten et al., 2017; Lunn Brownlee et al., 2017) and the power of reflection for improving this thinking (Buhel & Fives, 2016), we see utilizing reflection to help teachers develop awareness of the relationship between their understanding of the epistemic nature of scientific practice and their teaching of science as epistemic practice to be promising path forward.
CHAPTER 5

Final Conclusions and Implications

Educating scientifically literate citizens who are prepared to knowledgably participate in developing and evaluating solutions to address scientific problems is crucial for developing an engaged and informed society. This goal has spurred a focus on teaching science as practice (Lehrer & Schauble, 2015; NRC, 2012) and integrating the epistemology of the scientific community into science classrooms (Berland et al., 2016). Helping students understand science as an epistemic practice of building explanations about the world and helping them see their own actions in science classrooms as participating in this practice have become key goals. Much of the work to shift the ways of building knowledge in science classrooms to more closely align with the ways of building knowledge in the scientific community falls to teachers. Teachers are the ones tasked with creating learning environments for their students (Buehl & Fives, 2016; Remillard, 2005) and supporting students to participate in the authentic practice of science. The work presented in this dissertation has been concerned with what it means to effectively teach science as epistemic practice, in the hopes of providing insights into how to support teachers in this effort. Our goals have been to better understand (a) effective instruction that aligns with the epistemic practice of science and (b) how teachers conceptualize and reflect on their own instruction as supporting science as epistemic practice.

We used the Apt-AIR framework of epistemic practice (Barzilai & Chinn, 2018) as a theoretical lens to describe science as epistemic practice, to establish what participation in this practice looks like in classrooms and what students should learn about the epistemology of science, and to analyze teachers’ instruction for science as epistemic practice. We used this framework because it defines epistemic practice in terms of a community’s goals of constructing
knowledge and how that community strives to achieve those goals, highlighting both what someone does to participate successfully in science and the epistemology of science. For science education, the Apt-AIR framework addresses supporting students to participate in relevant, valued epistemic activities and to understand why these are important to scientific practice.

With respect to effective instruction, based on the Apt-AIR framework, we specified epistemic aims and ideals of science that are important for students to understand in order to aptly participate in scientific practice, and we synthesized prior research to describe how teachers might support these epistemic aims and ideals. Prior work has emphasized supporting students to participate in and understand the valued epistemic activities of the scientific community (Barzilai & Chinn, 2018; Berland et al., 2016; Lehrer & Schauble, 2015; Stroupe, 2015; Russ, 2014), but often left at a conceptual level is that learning science as epistemic practice requires understanding the connected nature of scientific practice. We bridge theoretical and applied work in novel ways to show how this connected nature of scientific practice can be analyzed empirically in classrooms. Using the lens of epistemic aims and ideals (Barzilai & Chinn, 2018), we have conceptualized specific ways that teachers might talk about the epistemic goals and criteria for building knowledge in science and identify these in five teachers’ classroom instruction. This has allowed us to explore how the connected nature of the epistemic practice of science is reflected in teachers’ instruction and, subsequently, in students’ understanding.

We found that teachers discussed epistemic aims and ideals of science with students in their classrooms. We identified that the connections teachers made between epistemic aims and ideals in their instruction and the consistency with which they discussed these with students may have been particularly important for helping students understand the epistemic nature and how to successfully participate in scientific practice. Our findings suggest that consistently emphasizing
(a) why the activities students are doing in science is important to scientific practice and (b) how the criteria for successful participation are all connected and in service of explaining phenomena are important features of effective instruction for teaching science as epistemic practice. Our results suggest that teachers might also need support to understand and more purposefully discuss these connections with their students. Examining teachers’ conceptions and reflections on teaching science as epistemic practice similarly revealed the importance of teachers being purposeful in helping students understand science as epistemic practice. We found that teachers wanted students to pursue epistemic aims in science and had knowledge of the epistemic ideals and processes used in science to achieve such aims. But our findings also suggested that teachers’ intention to help students understand why and how to participate in aspects of scientific practice may be especially important for enacting instruction focused on learning the epistemic nature of scientific practice. More research is needed to better understand how teachers are actively thinking about framing science as epistemic practice in their instruction and how to help teachers translate their knowledge of scientific practice into their classrooms.

The work presented in this dissertation offers contributions to our conceptualization of science as epistemic practice in classrooms, and specifically our conceptualization of instruction that is rooted in a situated, communities of practice perspective and aligned with the epistemology of the scientific community. The recommendations for instruction offered are promising for supporting students’ learning of scientific practice, and future research can help us understand how to promote this instruction in science classrooms. Insights into teachers’ conceptions of teaching science as epistemic practice shed light on the importance of teachers’ intentionality and awareness of their own instruction in making practice a focus in classrooms as well as external factors that can interfere with this goal.
Our findings show that teachers are taking steps in the right direction. Teachers valued epistemic aims in their science classrooms, they talked about these aims and the purpose of activities in science, and they helped students think about criteria for participating in scientific practice. But teaching science as epistemic practice was not the central focus. While teachers discussed and made connections between epistemic aims and ideals of science in their instruction, helping students understand how and why to pursue these aims was not necessarily a focus in their classrooms. Participating in scientific practice was something students did to learn content, which is positive, but in the face of challenges such as students’ interest and time pressures, learning content or ensuring that students completed activities seemed to outweigh learning science as practice. Others have found similar tendencies that teachers often engage students in scientific practice as a means to achieve other learning goals rather than participating in practice being the key goal (Sandoval, Kawasaki, Cournoyer, & Rodriguez, 2016). Such approaches to teaching scientific practice are “schoolified.” They are not aimed at enculturating students in the ways of building knowledge in science and helping students understand the epistemic nature of the scientific enterprise.

Changing students’ “schoolified” approach to learning science likely requires changing the “schoolified” approach to teaching science. Previous focus in science education on “the scientific method” has been criticized for misrepresenting science (Ford, 2015, Rudolph, 2005; Stroupe, 2015), promoting procedural and disconnected tasks that are inconsistent with the epistemic practice of science (Duschl, 2008; Windschitl, Thompson, & Braaten, 2008). While the educational research community has made much progress past the scientific method, many classrooms have not. Procedural, linear, task-based approaches may work well when the desire is simply to learn content or a skill, and they are well suited for the typical structure of schools, but
they do not help students understand the epistemology of scientific practice (Blikstein, 2014; Windschitl et al., 2008). These approaches likely persist in schools in part because learning content is what is valued on tests and the structure of school remains most conducive to short, fast, disconnected activities. Perhaps, then, we should not be surprised to see the implementation of a curriculum purposefully designed as an extended and connected investigation centered on learning scientific practice – such as the one used in our studies – unfold in classrooms without a desired focus on epistemic practice.

To really change this current state of affairs and teach science as epistemic practice in a way that makes enculturation in scientific practice central, teachers need to be supported and empowered to focus on practice as a primary learning goal in their science classrooms. Achieving this goal calls for action at several levels. First, teachers need to be supported through their teacher education and professional learning to understand and develop confidence in approaches to helping students learn how and why to pursue epistemic aims in science. Additionally, teachers need to be supported with curricular materials that allow for more open-ended investigations that foster the authentic ways of collaboratively building understanding in science. This calls for curriculum developers and researchers to better understand the optimal structure of such units and materials. Making epistemic practice central in science classrooms also means changing how students are assessed and what teachers are held accountable for teaching. Teachers like Mr. C recognize this and have begun to advocate for these changes in their districts.

“We want kids to be scientists in our classes. Right? We don’t just want them to be getting information and regurgitating it back to us. We want them practicing...If we want kids to be scientists, and we are looking at these NGSS standards, then why aren’t we
assessing them on the practice of science? Now if we focus on the practices of science, we are going to better ensure that all science teachers, middle school science teachers, in the district are focused on developing scientific thought and those practices in kids as opposed to a content grade” - Mr. C

Currently, teachers are held accountable for many things other than teaching practice. Being held accountable for students learning science content creates pressure to focus on science content and continue moving forward to cover all of the necessary content, and teaching scientific practice becomes an aside. As shown in our work, even if teachers want students to pursue epistemic aims in science, teachers have little time for the extended investigations that provide such opportunities for their students. Removing the pressures to focus on science content and complete activities requires changing this focus at district and policy levels. Educational standards for teaching “science practices” are a step in the right direction, but implementing these in a way that is not simply a new list of things that teachers need to check off is essential. This is not a new insight, but speaks to a larger and deeper change that is needed in science education to support a shift towards teaching science as epistemic practice. Valuing the goal of students learning practice and pursuing epistemic aims will need to be reflected at all levels of science education in order to actually change – from teachers’ actions and curricula in classrooms to educational assessments, standards, and policy.

Limitations

The work presented in this dissertation has several limitations. One limitation is in our application of the Apt-AIR framework (Barzilai & Chinn, 2018). We drew on prominent literature from fields of science education research and learning sciences to identify epistemic aims, ideals, and processes of the practice of science, but we acknowledge that there are many
scientific communities within different domains of science that have their own goals and ways of achieving those goals. Thus, the epistemic aims, ideals, and processes that we used in our application of the Apt-AIR framework, detailed in Chapter 2, do not necessarily reflect the epistemic practice of all areas of science. There are other aspects of the practice of science not addressed by our work that may be particular important for understanding and analyzing the practice of a given domain of science. Such nuances might impact the usefulness and generalizability of our findings and influence recommendations for how teachers support students’ learning of epistemic practice.

There are also limitations in our interpretation of the connections in the teacher and student networks presented in Chapter 3. We approached our analyses with a perspective that making more and stronger connections between various epistemic aims and ideals reflected a more sophisticated, connected understanding of scientific practice, and thus was better. However, this perspective does not consider that certain connections might be more important than others, or more important at particulars times and for particular activities. Our analyses do not address these potential nuances. Further, other perspectives on learning might argue that it would be more beneficial to teach aspects of practice in isolation first, and then help students understand the connections. That is, it might be challenging for students to understand the connections and relationships between epistemic aims or ideals without first understanding the aims and ideals of practice on their own. Focusing on teaching students how to participate in specific processes of scientific practice might be an important step to take before helping them understand how these aspects of practice are all connected and in service of the larger epistemic aims of science. From this perspective, teachers discussing various epistemic aims and ideals might actually be a productive strategy.
Additionally, we acknowledge several constraints in our methodology. Our small sample size of teachers from the same district limits the generalizability of our findings. While still informative as in-depth case studies, investigating the instruction and understanding of other teachers would be useful for making recommendations for the broader population of teachers. Further, we were not able to account for how teachers’ instruction prior to the composting unit used in our study might have influenced students’ understanding and participation in the epistemic practice of science in Chapter 3. The data collected in our work was from the end of the school year, and it is thus unclear whether and how teachers might have discussed the epistemic practice of science with students previously. Lastly, the codes we used in Chapter 3 to analyze teachers’ discourse did not exactly match the codes used analyze students’ understanding of the epistemic nature of scientific practice – this constrained our ability to more rigorously compare teacher and student networks. We were able to make qualitative comparisons between teacher and student networks based on overall patterns of the number and strength of connections, but we were not able to subtract or statistically compare teacher and student networks to better understand how teachers’ instruction related to students’ understanding.

**Future Directions**

We see several avenues of future research on teaching science as epistemic practice that build on the work presented in this dissertation and address several of the limitations discussed above. First, future work is needed to provide more nuanced analyses and discussions of how epistemic aims, ideals, and processes vary across different disciplines of science. We have presented a novel application of the Apt-AIR framework that specifies epistemic aims, ideals, and reliable processes of science, but these specifications may not be sufficient for all domains of science. We acknowledge that different domains of science have their own scientific
communities with varying epistemologies and can have their own goals, criteria, and ways of developing understanding. For instance, the epistemic practice of evolutionary biology might look quite different from that of physics, in that the ideals and processes for investigations and what constitutes sufficient evidence in these domains are different. Further defining and understanding these nuanced differences will be important for describing the epistemic practice of particular domains of science and for understanding how teaching science as epistemic practice might vary in these difference domains.

With respect to connections between epistemic aims and ideals of science, an important next step is to investigate which connections might be most important for students to learn and during what activities these connections are most relevant. Different activities (e.g., conducting an experiment versus generating questions) have different activity structures and are more closely related to each other; thus, different connections might be more important at different times or during particular activities. More work, both conceptual and empirical, is needed to explore questions of whether a teacher or student making more connections between aspects of practice is always better, whether all types of connections are equally important, and under what circumstances it is beneficial to emphasize certain connections. Since certain aspects of practice are more closely related than others, it might make sense for teachers to focus on particular connections that are most important for a given activity. Future work could explore the connections teachers make between aspects of epistemic practice during different activities to better understand which connections might be most important and relevant to support students’ understanding.

Additionally, future research could explore students’ understanding of the epistemic practice of science as reflected through their discourse. We assessed students’ understanding of
the epistemic and connected nature of scientific practice through a written post-unit measure. While informative, this measure did not show us how students were discussing epistemic aims and ideals during activities. This measure also did not provide students with an opportunity to demonstrate their understanding about the epistemic aims of science, as the question itself included an epistemic aim of science. Future work could look more closely at how students make connections between epistemic aims and ideals in their discussions during science activities to better understand how students learn science as epistemic practice. Analyzing students’ discourse in the same way (and with the same coding scheme) that we analyzed teachers’ discourse in Chapter 3 would also allow us to leverage powerful statistical analyses to compare student and teacher networks. Such analyses would make it possible to investigate more precisely the aspects of practice and the connections that students take up from their teachers’ instruction.

While there is still much work to be done, the body of research presented in this dissertation is an important contribution in the ongoing efforts of educational researchers and teachers to create classroom communities that help students learn and participate in the epistemic practice of science. Achieving this vision of science education will take a concerted effort from educational researchers, leaders, and teachers, but we are hopeful in the future.
References


Appendix: Interview Protocol

Teacher Knowledge of Science as Epistemic Practice Interview Protocol

Providing context

Describe a recent unit you taught in your science class or one from this school year that stands out to you. This will provide some context for some of the questions I ask you later.

Part I: Epistemic aims

1. What are the most important things you aim to teach students in your science class? For instance, at the end of this year, what do you hope your students have learned? Or in the unit you just described, what were the most important things you wanted students to learn? I don’t want you to necessarily think about the standards you are held accountable for or the particular rubrics you use in your curricula. Rather, what do you think is important for students to learn, what would you focus on with your students if it was truly up to you?

Potential follow up questions if teachers do or do not discuss students learning about:

Science content:

• If teacher does not discuss:
  o What about learning science content? Where does that fall in importance for you?

• If teacher discusses:
  o Why is it important to you for students to learn this?

Skills/practices/processes:

• If teacher does not discuss:
  o You mentioned wanting students to learn ____, are there any particular things you would want them to learn how to do in science? Skills or practices or processes?

• If teacher discusses (or after asking question above):
  o What particular types of skills do/would you emphasize with your students?
    ▪ What do you want your students to learn how to do in science?
    ▪ You mentioned wanting students to learn to solve problems in science – what do you mean by that? What do you want students to be able to do?
  o Why is it important to you that students learn these skills and practices?
  o Is that something you talk to your students about? Do you talk with your students about why they are learning these things or why you think it is important for them to learn these skills or practices?
    ▪ What are specific things you do to help your students understand the purpose of what they are doing?

Broader ideas about science (epistemic nature of science):

• If teacher does not discuss:
  o Are there particular things you would want your students to learn more generally about the discipline of science? Or about the overarching goals of science?
If teacher discusses:
- Do you think that your students understand how science is a process of developing explanations about the world?
  - How the different scientific practices/processes they engage in are all related to developing explanations?
- What are specific things you do/would do as a teacher that you think support this understanding?
- What challenges do you encounter when trying to support students to learn this idea? Or, what are the biggest obstacles you see in students learning/understanding this idea?
- Why is it important to you that students learn this?
- Is that something you talk to your students about? Do you talk with your students about why they are learning these things or why you think it is important for them to learn this?

Do you feel like you are able to focus on or prioritize these goals in your classroom? If not, why?

2. Do you discuss these goals with your students? How do you convey these goals to students?

Potential follow up questions:
- You mentioned wanting students to learn _____. Do you talk with your students about why they are learning these things or why you think it is important for them to learn this? Why?
  - What are specific things you do to help your students understand the purpose of what they are doing?
- What goals do you hope students set for their learning in science? How do you help students decide what goals they should adopt when doing science?

Part II: Epistemic ideals

3. Think back to the unit you described at the beginning. What were the important processes, skills, or practices that were important for students to learn and use to develop their scientific knowledge? What processes or skills did you want them to learn?

Generating questions
- What are specific things you do/would do to help your students learn how to write productive/good questions?
- How do/would you help them understand why writing questions is important in science?
  - Why the criteria that you mentioned are important?
- What challenges/obstacles do you encounter when trying to support students to learn these ideas?

Conducting investigations
• What are specific things you do/would do to help your students learn how to set up and conduct an investigation?
  o How to control variables?
  o How to purposefully plan/conduct trials?
• How do/would you help them understand why conducting investigations is important in science?
  o Why the criteria that you mentioned are important
    ▪ Why controlling variables is important?
    ▪ Why purposefully planning/conducting trials is important?
• What challenges/obstacles do you encounter when trying to support students to learn these ideas?

Analyzing data

• What are specific things you do/would do to help your students learn how to analyze their data after an experiment?
  o How do you help them look for patterns or relationships in their data?
• How do/would you help them understand why analyzing data is important in science?
  o Why the criteria that you mentioned are important?
    ▪ Why looking for patterns/relationships in data is important?
• What challenges/obstacles do you encounter when trying to support students to learn these ideas?

Constructing explanations

• What are specific things you do/would do to help your students learn how to write a scientific explanation? What information they should include in a scientific explanation?
  o How do/would you help students understand how to use evidence to support a claim?
  o How do/would you help students understand the difference between data and evidence?
• How do/would you help your students understand why constructing explanations is important in science?
  o Why the criteria you mentioned are important (why they need to include those pieces of information)?
    ▪ Why they need to use evidence?
• What challenges/obstacles do you encounter when trying to support students to learn these ideas?

Part III: Reflecting on videos of teacher’s own instruction

With the ideas we have been discussing in mind, I’m now going to show you a couple video segments of your own teaching during the compost unit you taught in your classroom. I know that watching yourself on video can be challenging/uncomfortable. But again, there are no right or wrong answers here. These videos are simply intended to provide some context for reflection and I am interested in your thoughts on what you notice.
As you watch each video, I’d like you to pay attention to how you supported your students’ learning. You might think about what your intentions were in this situation (what was your goal) and how you were helping students understand the purpose of the activity or how to successfully participate in the activity. You might also think about what you do in similar situations that occur in your classroom or what you might do differently in this situation. After each video, I’ll ask you about your thoughts and a few questions about what you noticed.

(Watch video)

5. What do you think your intentions were in this video; what were you trying to help students understand?

Potential follow up questions:

- Were there particular content or skills/practices you were trying to help your students understand?
- Why would that be an important thing for students to learn? OR Why is this an important thing you would spend time helping your students understand?

6. As you were watching, what were some specific aspects of your teaching that you think helped students understand the purpose of the activity or how to successfully participate in the activity? (can make this more specific based on the intentions they discuss in previous question).

Potential follow up questions:

- Did you notice something you did to help students understand the purpose of the activity they were doing?
- Did you notice something you did to help students understand the specific criteria/responses you were looking for here?
- Did you notice something you did to help students understand how they should be participating in this activity?
- Earlier, you talked about specific strategies like ___. Do you notice those here?

7. In similar situations in your classroom, what other ways might you support students’ to understand the purpose of the activity (what they are doing) or how to successfully participate in the activity? As you were watching, are there specific things you might do differently in this example?

Potential follow up questions:

- What would/could you do here to help students understand the purpose of the activity they were doing; understand the specific criteria/responses you were looking for; understand how they should have be participating in this activity?
- Are there particular challenges you see face in making that change?
- Earlier, you talked about challenges with ___. Do you notice those challenges here?