CHAPTER 4

# AN ACCOUNT OF TEACHERS' EPISTEMOLOGICAL PROGRESS IN SCIENCE

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We examine elementary teachers' inquiries in science in summer professional development (PD) workshops, as part of *Responsive Teaching in Science*, a three-year project supported by the National Science Foundation. The data, in broad view, shows significant progress in most teachers' disciplinary engagement. Our purpose here is to study epistemological aspects of that progress. Motivated by accounts of epistemological *resources* and *framing*, we consider evidence of local dynamics by studying teachers' work during the first summer workshop and the third. The analysis shows moments in the first summer that resemble the more extensive disciplinary engagement of the third. These moments were uncommon and short-lived, during the first summer, but they evidence intuitive epistemologies consistent with disciplinary epistemologies. We thus characterize teachers' progress in terms of expanding stabilities of emergent patterns of engagement.

*Teachers' Personal Epistemologies: Evolving Models for Informing Practice,* pages 89–113.

## INTRODUCTION

In this chapter, we analyze evidence of epistemologies in teachers' activities during the first and third summer professional development (PD) workshops of a three-year project. Motivated by accounts of *resources* and *framing*, we discuss complex dynamics that include but are not limited to epistemologies, with conceptual, social, affective, and material aspects; we do not presume teachers' epistemologies are stable or independent constructs.

We begin with a brief review of epistemological resources and framing. We then turn to data from our case study, the first and third summers of professional development from a project in elementary science education.

### *Epistemological Resources*

Most accounts of personal epistemologies have treated them as stable within individuals. Change, in these accounts, entails progress from one position to another. The positions are sometimes understood as stages of development (Belenky, Clinchy, Goldberger, & Tarule, 1986; Kuhn & Weinstock, 2002; Perry, 1970), and sometimes as beliefs, theories, or worldviews (Hofer & Pintrich, 1997; Hofer, 2010; Schommer, 1993; Schraw & Olafson, 2002). Hammer and Elby (2002) described such perspectives as "unitary" and offered an alternative, "manifold" account of epistemologies as variable within individuals. Rather than thinking of an individual as having *an* epistemology, they proposed attributing rich collections of epistemological resources that the individual may activate or not in different circumstances. For example, rather than attribute a unitary belief, such as the belief that all knowledge comes from an authority, Hammer and Elby (2002) attributed a variety of resources that may be active in different moments. A child asking her father "what's for dinner" would be tacitly activating a resource for thinking of knowledge as coming from authority. In other contexts, the same child may invent a name for a dog, or figure out the sum of 5 and 7, or infer from bowls on the counter that the dessert is ice cream —indicating resources for understanding knowledge as invented or as formed in different ways from other knowledge.

Thus from a resource-based view, different patterns of resources can be active in different moments. Louca, Elby, Hammer, and Kagey (2004) applied this perspective to understand how a third-grade class shifted from providing teleological descriptions about why leaves change color to looking for mechanistic explanations. The shift occurred after the teacher, Kagey, explained the difference between "why" and "how" explanations with an analogy to *why* she made cookies (for her birthday) and *how* (putting the ingredients in a bowl, mixing, etc.). The authors argue that the students' shift was not a result of a wholesale change in their beliefs, but rather that the teacher's description tapped into and activated different resources for understanding kinds of knowledge.

Similarly, Rosenberg, Hammer, and Phelan (2006) described two different "local coherences" of epistemology as a group of eighth graders worked to develop a model of the rock cycle based on what they had studied about sedimentary, metamorphic, and igneous rocks. At first, they approached the task as a matter of finding and relocating information from worksheets. The teacher, Phelan, seeing what they were doing, advised them to "start with what you know, not what the paper says" (p. 272). Following her prompt, the students started over. In what followed, they still referred to the worksheets, but they used the information in the service of telling a sensible, causal story. The authors argued that these two activities reflected two different coherences of epistemological resources: one they called "cut and paste," to select and create a sequence of facts and terms, and the other causal "storytelling," much closer to the disciplinary target of the rock cycle.

In these ways, the theoretical perspective of resources provided an underlying framework from which to consider moment-to-moment variability and multiple coherences in epistemologies. Understanding students as having rich collections of epistemological resources, rather than as a single position, suggests that they are capable of thinking in diverse ways.

Isolating particular resources, however, is of limited use for analyzing epistemologies *in situ*. The evidence supports claims about sets or patterns of resources more than claims about particular resources within those patterns. Thus Louca et al. (2004) argued the children's reasoning showed that they were capable of different epistemological positions, but they did not focus on identifying the particular resources involved in those positions. Rosenberg et al. (2006) were careful to present their resources-level description as an in-principle account of how fine-grained structures could activate in different patterns at different times. Sandoval (2005) described these as "practical epistemologies," "the epistemological ideas that students apply to their own scientific knowledge building through inquiry." (p. 635)

### *Framing*

Redish (2004) connected accounts of epistemological coherences to research on framing (Goffman, 1974; Tannen, 1993; Tannen & Wallat, 1993), which refers to participants' developing sense of "what is it that's going on here?" (Goffman, 1974, p. 8). Framing involves activating and adapting structures of expectation developed from prior experiences (Tannen, 1993). Framing is generally understood as dynamic, and frames "emerge in and are constituted by verbal and nonverbal interaction" (Tannen & Wallat, 1993, p. 60).

For example, on the first day of a course, instructors and students bring sets of expectations about what is going to take place. Their framings shape the ways in which they participate and respond to each other; in turn, their experiences shape their framings. Instructors and students give metacommunicative cues to establish and negotiate a shared framing, such as writing on the board or turning to ask a fellow student a question. These same cues that participants provide to each other can be evidence for researchers (McDermott, Gospodinoff, & Aron, 1978; Scherr & Hammer, 2009; Tannen, 1993).

Epistemological framing (Redish, 2004; Hammer, Elby Scherr, & Redish, 2005), then, is framing with respect to knowledge and learning. Subsequent accounts have discussed framing in classroom and interview settings to understand and explain the dynamics of students' and teachers' disciplinary engagement (Berland & Hammer, 2012; Hutchison & Hammer, 2009; Russ, Lee, & Sherin, 2012). In all, these accounts of epistemological resources and epistemological framing represent a shift from unitary views, in which individuals are characterized as being located at particular developmental stages or having particular, coherent epistemological theories. In contrast, accounts of epistemological resources and framing understand epistemologies as dynamic.

For our analyses below, it is important to be clear that an epistemological framing, meaning a sense of what is taking place with respect to knowledge, would generally depend on other aspects of framing as well. In this respect, the term *epistemological framing* may be misleading because it could connote an independent stability. That connotation can be appropriate in understanding specifically epistemological structures of expectations—as students, for example, abstract a notion of "doing an experiment" as a form of epistemic activity. More generally, however, we expect that epistemological *aspects* of framing interact complexly with conceptual, social, affective, and material aspects.

Moreover, these accounts often describe epistemological framing as distributed across a class or group, in contrast to attributing beliefs to individuals. As we noted above, Rosenberg, et al. (2006) described coherences of the group's epistemology, not of individuals within it. Similarly, Scherr and Hammer (2009) argued for considering the group of students as the unit of analysis. Frank (2009; Frank & Scherr, 2012) showed multiple stabilities involving groups of students and the materials they were using in an introductory physics laboratory.

Conlin, Gupta, and Hammer (2010) discussed how the scale of the relevant unit of analysis (e.g. from individual to group to class) may itself vary dynamically. They discussed how the data may provide evidence regarding what and who contributes to the stability. We find this approach particularly relevant to our analyses below, as we identify evidence of who contributed to the stabilities.

The need for accounts of change over time

Unitary perspectives on epistemologies have offered accounts of progress, either through transitions between developmental stages or transformations of beliefs or worldviews. However, while a framing perspective supports an understanding of epistemologies as dynamic, there has been little study of progress from this perspective.

In one case, Hammer, Elby, Redish, and Scherr (2005) describe "Louis," a student in Hammer's introductory physics course. At first, Louis studied "every word" of the homework solutions and memorized the textbook. After failing the first exam, he decided to implement the advice to make sense of the ideas as if he were explaining it to a ten-year-old, and the result was a dramatic improvement in his understanding and performance. Louis attributed his success to his change of approach and explained how, ironically, at the time he was memorizing he was advising other students in his role as a math tutor to approach learning as sense making. The authors speculate that Louis could tap into his experiences as a tutor to reflect on and reconstruct his own approach to learning (Elby & Hammer, 2010).

In another case, directly relevant here, Lineback (under review, 2012) studied how "Mrs. Miller" shifted in practices of responsiveness teaching fifth-grade science. Mrs. Miller ("Bonnie" in the data we present) was one of the teachers in the Responsive Teaching project we describe below. Lineback's evidence shows moment-to-moment variations in Mrs. Miller's practices. It also shows progress over the three years of the project in shifting patterns of responsiveness. Lineback characterizes Bonnie's development as a growth of some patterns—modes of attention she comes to enter more often—rather than as a linear or monotonic change in approach.

In this chapter, we study epistemological aspects of change evident in teachers'participation from the first to third summers of the project. While most research on teacher epistemologies examines interviews and surveys for teachers' professed epistemologies and/or their enacted epistemologies *in their teaching*, we looked at teachers' epistemologies *within their own engagement in science*. Like Lineback's study of Bonnie's in-class practices, we will show evidence both of moment-to-moment variations as well as of shifting patterns in teachers' enacted epistemologies. We analyze the data to show local stabilities, which we describe and understand as epistemological aspects of framing, during whole-group and small-group science conversations in the two PD workshops. We argue that the teachers' progress largely entailed their becoming more stable in framing what they were doing in ways that were only intermittently evident in summer 1.

## *Background and Methodology*

The professional development workshops were a part of a project in elementary science education funded by the National Science Foundation.[1] The main goal of the PD was to foster teacher practices in *responsive teaching*—making space for, recognizing, and responding to student thinking. To this end, the PD focused on three main activities: 1) engaging teachers in their own inquiries, 2) watching classroom video to practice noticing and interpreting students' ideas and reasoning, and 3) considering possible responses to these ideas and reasoning.

The PD consisted of 1–2 week workshops across three summers, as well as bi-weekly meetings during the school year. Prior work from this project has focused on data from project classrooms, to study responsive teaching and student inquiry (Hammer, Goldberg, & Fargason, 2012; Jaber & Hammer, under review; Lineback, 2012; Maskiewicz & Winters, 2012). Maskiewicz (2015) also examined the facilitation of teacher inquiry in the second summer workshop as part of a practitioner reflection piece.

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[1] For more information, see cipstrends.sdsu.edu/responsiveteaching/index.html.

The science inquiry portion of the workshops often started with a launching question to engage teachers and PD staff in developing their own understandings about natural phenomena. For example, the first summer PD workshop started with the question: what ways of connecting bulbs wires and batteries make the bulbs light, and what ways do not. Most of the teachers' time was spent either in whole-group or small-group discussions. The PD staff encouraged the teachers to pose questions of their own, to draw on analogies using everyday reasoning, to develop models and to use these to make predictions, and to design their own experiments; they emphasized teachers' communicating their ideas to each other and then examining, debating, and refining the merits of each other's explanations.

The first summer workshop centered on teacher inquiry about batteries and bulbs. While we do not present data from the second summer here, the teachers discussed composting and decomposition. In the third summer, the teachers split into two groups, based on their interests. The larger group of eight teachers, which we focus on here, was interested in studying the water cycle and came up with the launching question, "Why doesn't it rain more in San Diego?" A smaller group of four was interested in studying electrostatics using a curriculum that guided exploration with everyday materials such as cellophane tape, plastic straws, and foam and aluminum plates (Morse, 1991).

We present data only from the rain group here for two reasons: first, most of the active teachers from summer 1 were present in this group and, second, there was more noticeable progress in the teachers' epistemological engagement. We list the teachers who participated in each summer in the table below. Three teachers, Kerri, Kim, and Sharon, joined the project in the second year. Of the staff, David facilitated the summer 1 work on electricity, with April participating and Janet observing by Skype. Janet facilitated the rain group in summer 3, with April again participating, but David was working with the electrostatics group.

From our interactions and experiences in these summer PD workshops, we noticed dramatic differences in the ways the teachers participated between the first and third summer, prompting extended video analysis of the differences in teacher engagement.

The data for this analysis came primarily from over 40 hours of video records of the workshops. We produced content logs for these videos, demarcating portions to revisit based on an initial sense that there was evidence of teachers' enacted epistemologies. We revisited these portions more carefully, and, seeing general patterns as we document below, we selected representative episodes to transcribe and annotate, recording speech as well as participants' bodily positions, gestures, and prosody. Based on these features of teachers' and PD staff's interaction, we developed accounts of the different ways teachers and PD staff were interpreting the inquiry tasks. We triangulated our interpretations of summer 1 videos with videotaped debriefs of the PD staff at the end of each workshop day. We then used our analysis to further refine our claims about the overarching patterns of teacher

TABLE 4.1. Teachers and PD Staff in Summer 1 and in the Rain Group in Summer 3

| **Summer 1 teachers** | **Summer 3 teachers in rain group** |
|---|---|
| Bonnie | Bonnie |
| Carolyn | Carolyn |
| Donna | Donna |
| Dorothy | Dorothy |
| Stacy | Stacy |
| Alice | Kerri (2nd) |
| Chris | Kim (2nd) |
| Kathy | Sharon (2nd) |
| **Summer 1 PD staff** | **Summer 3 PD staff in rain group** |
| David | Janet |
| April | April |
| Janet (by Skype) | Jen (grad student) |
| Jen (grad student) | |
| Kweli (grad student) | |

Three teachers joined the project in its second year, as noted.

engagement. We went back and selected discrepant episodes to transcribe and analyze, further iterating our claims about the stability of teachers' framings of science as inquiry.

### *Summer 1 and Summer 3 Analysis*

In the following analysis, we argue that the progress made between these two summers was primarily in the stability of teachers' scientific inquiry. We show that the teachers exhibited epistemologies for scientific inquiry in both summers 1 and 3, but with important differences in duration and support: In summer 1 episodes of disciplinary engagement were uncommon, brief, and involved significant support by PD staff. In summer 3, the episodes were of much greater duration and teachers initiated and sustained much of their inquiry themselves.

### *Stability and Instability of Scientific Inquiry in Summer 1*

We present three episodes from summer 1. In the first two episodes, we show typical science conversations from summer 1 in which teachers challenged the nature of the inquiry task or struggled to understand it. These episodes show evidence of teachers' framing the activities at epistemological odds with science. In the third episode, we show a moment of conversation, atypical that summer, of teachers' beginning inquiry. For this moment, the epistemological aspects of the teachers' framing were consistent with science.

### *Episode 1: Explicit Challenges to Inquiry*

The first summer session was punctuated with challenges about what was happening, often over the idea of teachers working to figure things out for themselves. On Day 2, for example, after the whole group had just finished recounting the results of different battery and bulb set-ups they had tried, David began to suggest that the teachers split again into small groups to consider patterns in the findings. Donna interrupted with a question:

| | |
|---|---|
| Donna: | Are we going to have some background knowledge on this—Are we—Are you going to build- |
| David: | Are you going to have some background knowledge- |
| Donna: | I—I would like to—Are you going tell us a little about how this works or are we going to just, like, [grimaces]. It worries me that I keep hearing this word over and over again. And I don't know what it means. |
| David: | Which word over and over again? |
| Donna: | [exaggerated whisper] Circuits! |

Donna's question challenged the idea of their pursuing inquiry without having "background knowledge"; she felt David should "tell us a little about how this works." Her comments suggest an epistemological stance that instructors can and should provide knowledge for students.

Other teachers voiced similar concerns at other points during the first summer. Finkelstein (2013) documents other such moments from this professional development project, as part of her study of "relational dynamics" between the facilitators and teachers. For example, at the start of this same day, Bonnie had expressed frustration about the professional development more broadly, stating that she wasn't sure how it "fit in" with what she was trying to accomplish in her classroom. For another example, on Day 4 Stacy expressed her desire for "closure." She claimed she needed the "answer," in part because that is what she needs to teach her students to prepare them for tests.

### *Episode 2: Struggle to Understand the Task of Looking for Causal Explanations*

Another pattern during the first summer was that teachers, in trying to cooperate, had trouble understanding what the facilitators were asking. On Day 3, for example, to follow up on the teachers' finding from Day 2, David asked them to work in small groups to try to understand why there needed to be two connections between the battery and the bulb for the bulb to light—in other words why there had to be a "complete circuit."

David suggested they might find it helpful to think of analogies to more familiar phenomena, and two teachers asked for clarification: Was the point to come up with analogies instead of "real science"? Was it to make the science more "real world" for students? David reiterated that the task was to come up with ideas for themselves.

Despite that clarification, the evidence from small-group conversations suggests that the teachers shifted among several interpretations of the task. At times, for example, some teachers returned to framing the task as about finding ways to explain "a complete circuit" to students. At other times, teachers looked for superficial analogies to moving circles, such as a Ferris wheel or a water wheel, without regard to mechanism. There were also frequent references to what "he wants" and what "he said," suggesting that their forming of these analogies were more in the service of satisfying David's request than of considering possible explanations. None of the groups entered stably into the sort of sense-making David had in mind, although their own questions about what makes the bulb light sometimes arose in their discussions.

Shifting from sense making to other interpretations of the task occurred often during the first summer workshop: the teachers struggled to understand the work David was asking them to do. They shifted to doing something that, apparently, seemed appropriate to them in the moment, such as discussing how to present information to students. As such, for much of the PD the teachers did not participate in scientific inquiry.

***Episode 3: Beginnings of Authentic Science Engagement***

There were, however, episodes of teachers' engaging in what we consider the beginnings of science, against the general patterns. We present one of those here. Because our arguments depend on this evidence, we present it in some depth, in three segments of activity.

Surprising results: "We were expecting it to light"

On Day 4, after a session of small group explorations, April[2] (staff) and Kathy presented their work. Kathy spoke first, describing various arrangements they had tried with the battery, bulb, and wire, identifying which arrangements did and did not light the bulb. April then asked to draw one more, which she said had surprising results.

April went to the whiteboard at the front of the room to draw a battery and bulb arrangement using only one wire. She connected the wire to both ends of the batteries and twisted the middle of the wire so it was touching both the tip and threads of a bulb. She explained that she was "super confused" because the bulb didn't light, despite the fact that the set-up had met conditions the group had earlier concluded from the evidence: A bulb will light if there are two connections to a battery, one to the tip of the bulb and one to a point of contact on the side of the bulb.

[2] April's expertise is in biology; this was new subject matter for her. Thus she was participating largely as an expert learner in science, and her participation constituted a kind of tacit facilitation, modeling practices of inquiry.

April: It had to be the tip and the thing, but as soon as we tried to use one wire, the bulb in the middle, I touched the side AND the tip, we were no go.

David: And I'm hearing in your tone of voice you don't have an explanation as to why. That seems surprising and puzzling to you.

April: We were expecting it to light because we were touching all the things we were supposed to touch.

April thus highlighted an inconsistency between the group's understanding and their results, a bid for a shift in activity from sharing results to making sense of them. By expressing her own confusion, she problematized the group's understanding of batteries and bulbs. Moreover, in their interactions, April and David modeled and made explicit epistemological and affective aspects of scientific inquiry: April referred to the group's earlier accepted ideas about circuits, stating that she expected consistency across situations; David highlighted the problem, a lack of an explanation, and openly empathized with her feelings of puzzlement, supporting her bid for the group to try to make sense of the results.

Developing an explanation: "I got it!"

The teachers started to talk about possible explanations, and Bonnie exclaimed, "I know it. I got it…. Path of least resistance. It's going to bypass the bulb altogether and circle right back to the battery, because it's just one wire. It's just going to ignore the—It's going to ignore the light bulb."

Stacy, Carolyn, Jen, and Chris all affirmed her explanation, either by nodding, saying "I get it", or summarizing her statements. Donna, however, voiced her confusion about Bonnie's explanation: "That I don't get." David stepped in for a moment as facilitator.

David: So [to Bonnie] you have a challenge of articulating your idea. And [to Donna] you have the challenge of understanding her reasoning…

Bonnie: It's like doing this. [Grabs battery and one wire to make a circuit with no bulb—see Figure 4.1] What they did, because this is one wire, it'd be just like doing this [indicating a path]. This is the circuit. The fact that you put the bulb there, ha—it's gonna bypass that bulb because that bulb—it's like that bulb is not even there.

Donna: Why?

Bonnie: Because it's—the wire takes precedence over what you've added on.

Donna: But why?

Bonnie: It's like a train track, alright, in a trainyard, you've got a train track where the train goes this way, [gestures in large circle],

FIGURE 4.1. Snapshot of Bonnie holding up a battery and wire to make a circuit without a bulb.

goes a way big loopy, but you want it to go the shortcut way to unload.

The teachers had immediately responded to April's problem by brainstorming reasons for why the bulb did not light. When Bonnie first voiced an explanation, other teachers responded only with statements that they did or did not understand. David then pushed the teachers to better articulate their explanation and hold each other accountable for its clarity, including identifying the roles for Bonnie and Donna.

From there, the exchange between Bonnie and Donna lasted several conversational turns, evidently around mechanistic sense making. Bonnie offered a simplified model to explain what she meant; Donna pressed for a causal explanation of why the electricity bypasses the bulb. When Donna was not satisfied by Bonnie's stating a rule, "the wire takes precedence," Bonnie came up with an analogy. Unlike the earlier analogies that David tried to instigate, Bonnie's had a clear meaning in helping her articulate a mechanism: She used the train tracks to highlight the "shortcut" that the wire provides in April's set up, likening the bulb's path to a longer loop for the train.

Garnering evidence to support the explanation: "It doesn't need the bulb…"

Bonnie, Stacy, and Carolyn elaborated on Bonnie's reasoning, suggesting that the electricity would bypass the bulb as if a switch was flipped or a gate was closed. Then Kweli (staff) asked a question to clarify the explanation.

Kweli: So somehow having two wires forces the electric current to go through the light bulb, but having one wire cause—makes it—bypass the light bulb. Is that right?

April: I have a problem with that….

Bonnie: Well, see I can feel heat right now, through this wire, right here. [Holds up battery and wire set-up] So this is already a connection, it's already a circuit, a complete circuit… The gate over here has been closed, to the light bulb.

Donna: Because the wire's twisted?

Bonnie: Because it's easier.

Donna: Not because the wire's twisted.

Stacy: No, just because it's trying to find—it's going its direct path. It—it—it doesn't need that diversion. [Other teachers in background talking, Jen goes to board]

April: But Kweli says, why do you suddenly need it when there's two wires?

Bonnie: OK, Donna, here's what might help. This circuit doesn't need this light bulb to work. It doesn't need the light bulb to complete the circuit. With two wires, it needs the light bulb to make the connection.

The conversation continued, as Donna, April, and Kweli all indicated that they understood. Other teachers and PD staff added on to Bonnie's explanation, eventually cheering and slapping high-fives at their sense of success, based entirely on their own assessment.

In this exchange, Bonnie, Donna, and Stacy persisted in developing an explanation for why the bulb did not light, drawing on analogies, finding and citing evidence, and seeking mechanisms. Bonnie offered the evidence of heat from the wire to support her account that a battery and wire without a bulb still made a connection. Donna, asking "Because the wire's twisted?", seemed to be trying to understand what in the circuit corresponded to the "switch" or "gate" that Bonnie and Stacy had proposed. Her persistence in asking Bonnie and the other teachers to explain not just what happened—the electricity bypassed the bulb—but precisely why it happened, suggests that she was invested for the moment in obtaining a clear and causal explanation.

Thus, Kweli's question seems to have prompted the teachers to address the explanation in a new way. Bonnie expanded her explanation to address the apparent inconsistency: with two wires, the bulb is needed to connect the circuit, but in April's one-wire set-up, the bulb is not needed.

***Evidence of Different Epistemologies***

This episode as a whole, we argue, shows teachers' seeking, constructing, and refining mechanistic explanations for the phenomena they had observed, supporting their explanations with empirical evidence, and celebrating their achievement based on their own assessment of its coherence—there was no instructional confirmation that they were correct. In these ways, their actions were evidence of epistemology consistent with the epistemic aims, values, and practices of science

(Chinn, Buckland, & Samarapungavan, 2011), including that knowledge about electric circuits, can come from their own experimentation, reasoning, and analogies to familiar causes and effects.

As we have said, this was not the predominant pattern over the first summer. Furthermore, we do not see the teachers' engagement here as progress in any stable sense. In fact, David had difficulty getting the teachers to build from this episode the next day: They exhibited patterns more like those in episodes 1 and 2. When he asked them to summarize the discovery they had celebrated, the teachers were hesitant and quiet. They had little to say connected to their empirical results and explanations. For instance, Donna stated that she had learned that electricity moves in a one-way path through the battery, bulb, and wires. In contrast to the previous day, none of the teachers questioned this new idea and no one offered evidence to support it. When pressed by David about how she came to believe this model, Donna said she accepted it because another teacher had told her. Despite his repeated recalls to their epistemological and affective markers from the previous morning, the teachers did not seem to return to the pursuit of articulating their understanding of what causes or prevents a light bulb to light. Only later in the day did some teachers working in small groups begin again to take up the sort of inquiry we saw in episode 2.

In moments such as we presented in episode 3, the teachers framed what they were doing in ways that showed quite different epistemologies from the general patterns. These are evidence of significant variability. From a resources perspective, this variability is to be expected: Particular situations can activate different resources for understanding knowledge.

### *Stability of Inquiry in Summer 3*

There was significant progress from summer 1 to summer 3, for most teachers in the project, and in particular for the rain group, evident in the ways they participated in the inquiry. We present representative episodes showing how teachers initiated, evaluated, and sustained their inquiry. We argue that the implicit epistemologies of their work in summer 3 were similar to those in the unusual moments of summer 1, and that the main progress was of stability.

In the first episode, we present excerpts from the first day of summer 3 to show that the teachers readily engaged in and took ownership of the inquiry from the start, again in ways consistent with disciplinary epistemology of science. The second episode is from Day 2, showing teachers acting to restore the conversation to such inquiry, in response to a moment of digression. Finally, we present excerpts from an extended discussion across Days 3 and 4. We show how the teachers persisted in extended inquiry across these two days, maintaining conceptual and epistemological coherence in their engagement.

### *Episode 1: Teachers Readily Engaged and Took Ownership of Their Inquiry*

*Redefining the Question*

Day 1 started with the broad question: why doesn't it rain more in San Diego? After several minutes of brainstorming individually and in small groups, the whole group came back together and discussed a range of possible considerations. About 10 minutes into this discussion, Donna made a bid to recast their pursuit:

> Donna: So, I'm wondering whether, it might help us to go back a little bit, before we try to figure out why it doesn't rain more in SD, and figure out what makes it rain. Because if, because if we start all talking about all these things and we're not clear, … Just in general. What are the things you need to have to make it rain?

This led to a burst of questions about what they thought they needed to know. April: "What's a cloud made of? And why is it in the air and not on the ground?" Carolyn: "Why do some clouds collect water and others don't then?" Donna: "We have clouds come in and out all the time, why don't they rain?"

Somewhat like April's bid in episode 3 of summer 1, Donna's bid here problematized the group's understanding of the phenomenon of precipitation. She evaluated their current discussion and anticipated the difficulty of continuing along this path. Furthermore, her questions focused the pursuit on developing a causal explanation: What makes it rain? She highlighted a particular aspect of the mechanism to pursue: what are the entities necessary for the phenomenon?

In this way, Donna was playing an agentive role, not only for coming up with ideas and explanations, but also for defining the question they were pursuing, and others joined in. As in episode 1 of summer 1, she evaluated what she and the group understood about the phenomena. However, in summer 1 she was addressing David, asking if he would provide background knowledge. Here she was addressing the group, asking that they focus their inquiry on why rain happens, as preparation for their thinking about why it does not.

*Generating possible mechanisms*

Donna's move got the group thinking of possible mechanisms and providing evidence to support their ideas. We present one excerpt from what was an extended discussion:

> Bonnie: So if you have a cloud, means if you have water vapor in the air, you have a cloud. There's always going to be a movement of air within a cloud. Always. So as that movement of air—it's going to move up, it's going to always move up and down—when it gets cold it's going to drop again, right? So, if you have enough moisture in the air, that movement is going to get heavy enough that it's going to cause that moisture to drop.…

Sharon: So is there water in a cloud? Is there liquid in a cloud?
April: That's the question.
Bonnie: Yes. There is liquid in a cloud. That's why you can see it. If it's not liquid, it'd just be water vapor, which is a gas.
Donna: Yeah, I mean we've got water vapor here and we can't see it, so if a cloud is just water vapor, how could we see it. That's [what I think about it].
April: But if it's a liquid, how's it in the air?
Bonnie: Because the updraft keeps it in the air.
April: If I took a drop of water and I tossed a drop of water in the air, [it's going to come back down again.]
Bonnie: The wind's updrafts keeps it in a motion. It just keeps it going up and down. You can duplicate that, I'm sure that you could duplicate that with something on your surface, the same kind of motion.

Bonnie identified possible entities and processes for a causal account of rain: water vapor in the air and movement of air within a cloud. She suggested a mechanism for why the air in a cloud would move up and down: As the air gets colder, it will drop. She then speculated that with enough moisture, the air would get too heavy, causing the moisture to drop. While her explanation needed more filling out to explain what causes the movement of air and how air supports the moisture, her account showed how she engaged in generating ideas to explain a phenomenon.

In addition, Bonnie and Donna drew upon their everyday experiences to support their idea that liquid must be in the cloud, not gas. Bonnie first proposed that it must be liquid in a cloud because we can see it. Donna added to this explanation by contrasting the water vapor in the air in the room with what we can see in a cloud.

This snippet shows the teachers engaging in practices they had mostly struggled with at the start of summer 1, including generating mechanisms and shopping for ideas from their everyday experiences. While the first snippet showed that they took ownership of the questions to pursue, this one showed their engaging in the pursuit. April was part of this activity, but she did not initiate it. In contrast to the start of summer 1, when it was difficult for the staff to induce or maintain the teachers' inquiries into phenomena, in summer 3 it happened easily, evidence of this framing becoming more stable.

### *Episode 2: Teachers Held Each Other Accountable to Their Overarching Pursuit*

In this episode, we provide evidence of the teachers' stability in their framing, based on how they respond as a group to one teacher's shift to a different conversation.

At the start of Day 2, Bonnie wanted to share what she already knew about precipitation. She came to the board and drew a diagram of a demonstration she had used in her class (see Figure 4.2): There was a clear container with a layer of water at the bottom, an empty dish in the middle, and ice sitting on plastic wrap covering the top. Bonnie explained how water vapor rose, collected on the inside of the plastic wrap, and then dripped back down into the dish. She then shifted to talk about what she observed in the classroom, describing the modifications her students made to the set-up and their level of engagement. When she finished, the teachers questioned her about the demonstration:

Sharon: Can you talk to how—can you take that and draw the lines for me to real life? Cause we—you know, we don't live in that box. I—I—I'm sure there is a line, an analogy, you know what I mean? I just don't know if I get it, yet.

…

Bonnie: This would be, your ice cubes would be your cloud, alright? So—

Sharon: But, can you—Sorry.

Bonnie: What what.

Sharon: I don't—because to me like, clouds aren't ice cubes, so how does it—how—what's the—

Bonnie: It can be. When it snows, what do you think is in the clouds? It has to be frozen, whatever's in there.

…

Donna: I guess ultimately you could ask, why did you put the ice there? What was it—

Bonnie: Why the ice— … Why ice? Ummm, I think to speed up the process, really?

Donna: And how does it speed up the process?

Bonnie: And actually, you can actually see the—the condensation underneath it. So it just, just, it made the process work a lot faster.

Donna: Because why?

During her presentation, Bonnie focused more on how the demonstration worked in the classroom than on sense-making about rain. This had happened often in summer 1, that conversations veered toward classroom teaching, rather than teachers' own sense-making.

Here it was Sharon and Donna—not the PD staff—who held Bonnie accountable to the overarching question and shifted the discussion back to their inquiry. Sharon asked for thought about how ice cubes in the model could connect to clouds. Donna asked about the mechanisms underpinning the demonstration. She first questioned the role that ice played: "why did you put the ice there?" She then pressed for a causal explanation: "how does it speed up the process?" Other

FIGURE 4.2. Bonnie presenting her evaporation and condensation set-up.

teachers also jumped in to redirect the conversation back to sense making about rain, either by voicing support for these questions or offering up possible ideas.

In this way, in this episode, the teachers as a group acted to maintain the activity of inquiry, evidence that, again as a group, they had a sense of the activity. In other words, the teachers' agency here is evidence of their epistemological framing: They worked to correct a divergence from what they understood to be taking place, in particular with respect to knowledge. We say as a group, because there is evidence of individuals varying in moments, such as Bonnie here.

***Episode 3: Extended Constructing and Critiquing***

The previous two episodes show teacher engagement on a time scale of sessions within a day, ~30–45 minutes. We include one final episode as evidence the teachers maintained their sense making from one day to the next.

On Day 3, Kerri introduced the idea of relative humidity, drawing on her experiences in a steamy shower room and her understanding of the rainforest. She suggested that there is only so much water that air can hold: "I still think there's an absolute humidity point that you hit. And air can only hold so much water. There's a point where there's too much water vapor." Kerri connected these ideas to earlier topics in the discussion, including their observations about how a cold water bottle will condense liquid on the outside, while a room temperature bottle will not. She suggested that the air outside of the cold bottle would have a lower "saturation" point because of its lower temperature.

These ideas led to an extended discussion about the mechanisms by which matter can change state. In particular, a conversation about the role of temperature, pressure, and "saturation" persisted across the next two days. At one point, Donna offered a different perspective on the role temperature plays for precipitation.

> Donna: I think the temperature is just changing the state of the matter. The molecules are just losing energy. And there—and that they're just becoming liquid because they're just losing energy. Because the temperature's down farther.
>
> …
>
> Donna: I don't think you need to have saturation for that to happen. I don't—
>
> Carolyn: I think she's just saying that saturation level in the air changes based upon temperature.
>
> Donna: What is saturation?
>
> Carolyn: If I'm a sponge, if I have a smaller sponge, or if I have a sponge with a lot of holes in it, it's going to have a different saturation than a sponge with tiny little holes.
>
> April: The amount it will hold without dripping.
>
> Carolyn: The amount it will hold.
>
> Donna: I really don't see the connection.
>
> Sharon [to Kerri]: But are you suggesting that if you, like you can create liquid from a gas just by having too much gas in the air—too much water vapor in the air, that creates a liquid, regardless of temperature?
>
> Kerri: Yeah. I think you go to the rainforest, it's steamy. And there's a reason it's steamy, like the air can't hold any more.
>
> Carolyn: It's why you're walking through and it's just—
>
> Kerri: Yeah, steamy.
>
> [Carolyn]: And that might explain [Washington] DC then too.
>
> Janet (others overlapping talk): So what do we see that—
>
> Donna: I think, maybe, what we need to talk about, what does "air can't hold any more". What does that mean? Air can't hold anymore. What does that mean? Air can't hold anymore.

Here Donna argued that temperature just changes the state of matter, rather than changing the saturation point. Discussing the differences between these two possible explanations, teachers were agentive in practices the facilitators had been promoting: Donna and Sharon pressed for clarity of the explanation of saturation; Carolyn offered an analogy from their everyday experience to shed light on a possible mechanism; and Kerri drew on her understanding of other geographical climates—namely the rainforest and Washington DC—to support her explanation. The teachers all engaged in these practices in the service of making sense of saturation, as opposed, for example, to engaging only in the service of pleasing the facilitators.

The teachers continued talking about temperature-dependent saturation points for the rest of Day 3, considering what it means for the air to "hold water" and the implications of their ideas. At the start of Day 4, continuing the discussion, Stacy described her understanding of why cold air cannot hold as much water:

> Stacy: In the warm air, just as in the convection cell, in the earth, when they're warm you have more space in between, so they're lighter, less dense. Which means more space in between, that's what I'm thinking. In cold, just like in a convection cell, as it gets away from the heat source and it's colder, just like in—in air, I don't know if they're the same, I'm just guessing, that when cold air, there's—they're more condensed, heavier, so less space in between. And that's why cold air holds less moisture than warm air.

Here Stacy drew on ideas the teachers had discussed, about hot air rising and cold air falling, as well as on her understanding of a convection cell. She knew that hot air was less dense and cold air more dense, and she used that knowledge to propose that the cold air has less space in between the air particles than warm air. She then linked this changing distance between particles to why cold air holds less moisture. Stacy had not been a major player in the discussion at the end of Day 3, yet she took up this inquiry direction and made connections to earlier conversations and ideas.

Her presentation led to more questions about whether moisture in the air is a liquid or vapor, whether saturation is the cause of condensation, and whether a physical barrier might also cause a change in the state of matter. With this diversity of ideas in play, Sharon made a bid to refocus their discussion back to their questions from Day 3. She recapped and expanded on the two different mechanisms proposed for why water may change states in cooler air.

Kerri challenged the idea that these are two different mechanisms, arguing that they both rely on the same premise: less space. April suggested they consider space and temperature separately, and Kerri proposed an experiment to see whether compressing air (reducing the space) would produce water droplets. Other teachers had other ideas, so they split into small groups for various investigations. Kerri and her group found a syringe with a cap and used it to show condensation forming on the sides when they pushed the plunger in the capped syringe. This finding led to another 1.5-hour large group conversation on the relationship between pressure, temperature, and changing the state of matter.

Throughout, the teachers continued to bring in their own experiences, of pressure cookers, changes in boiling temperature based on altitude, and seeing your breath on a cold day. They persisted in looking for mechanistic explanations: Donna spoke of energy and molecule movement to explain how raising the temperature of water results in a change of state. They also continued to direct their pursuits: Donna made a bid quickly after the group reconvened to have them write a clear succinct description of what they observed with the syringe before discussing the implications. They also evaluated their own progress: Dorothy commented that she noticed that they were talking about temperature and pressure separately and thought that it might be productive to think about them working together.

By Day 5 they returned to the question of why it doesn't rain more in San Diego, drawing on their explorations about precipitation, temperature, pressure, and condensation.

## DISCUSSION

The PD staff in this project hoped for teachers to experience and see doing science as a pursuit they could take up themselves, a pursuit of tangible, coherent understanding of natural phenomena. They wanted teachers to try things, to come up with ideas of their own, drawing on their very rich conceptual resources, including their knowledge about phenomena and their causes and effects.

The teachers, however, evidently began the workshop expecting that knowledge would come from the staff as authorities, that doing well would mean getting "the right answer," and the staff would know what that is. Their expectations were evident in their explicit challenges to the tasks, as teachers in summer 1 asked or argued that the staff should play these roles. Their expectations were evident as well in the teachers' difficulties understanding what the facilitator had in mind, shifting for example to talk in terms of instructional strategies for their students, rather than engaging in their own inquiries.

These expectations clearly involved epistemology, such as that knowledge comes from authority. By unitary accounts of personal epistemology, the evidence would suggest that the teachers held some naïve and problematic beliefs, or that they were at early stages of development. By the resource-based accounts that motivate our analyses, the evidence suggests *stabilities*—for the teachers as a group as well as for at least some individuals. In a broad view, these interpretations are similar, but there are important differences between them.

In particular, from a resource-based view, other dynamics are possible. The epistemological resources people apply depend on how they experience the situation, how they frame what is taking place. As they frame what they are doing in different ways, they tap into different resources, understanding knowledge in different ways. There are, we expect, productive epistemological resources for science evident in everyday reasoning, which often involves causal sense making ("Why is the floor wet here?" "What's making that noise?"), attention to evidence, and expectations of sensible explanations.

This view, in fact, informed the design and implementation of the PD. Had the staff viewed the teachers' resistance to or struggle to understand inquiry as evidence of "misconceptions" or committed intuitive theories, the PD might have adopted an approach of eliciting those misconceptions, problematizing them, and guiding the teachers' construction of new epistemologies. On that view, a naïve epistemology would be an impediment until it was addressed. While there was some discussion about extant views of science, more of the PD strategy focused on tapping into productive epistemologies in the teachers' repertoire, productive in particular for beginning scientific inquiry.

The evidence from summer 1, like the evidence in earlier studies of students (Louca, et al., 2004; Rosenberg, et al., 2006) supports a productive epistemologies view. In particular moments, the teachers engaged with phenomena and ideas as nascent scientists. In the third example we described from summer 1, Bonnie, Donna, and Stacy were captured by an incongruity and proposed ideas for how to explain it. They were not oriented toward teaching science or figuring out what the PD leader wanted; they were focused on the bulb and the wire, why the bulb did not light in this arrangement but did in others. Much as they might sense-make when noticing something incongruous at home, they did in moments during summer 1.

Accounts of epistemological resources and epistemological framing have focused significant attention on such phenomena, of short time-scale dynamics; it has been much of the empirical basis for the perspectives. These accounts have done little to date to document and discuss progress over longer time scales. Having established that epistemological dynamics can vary moment-to-moment, what is it that changes over months and years?

Our purpose in this chapter has been to do that, to document and discuss progress, comparing the teachers' reasoning and behaviors between the first summer and the third. We focused on teachers' engagement, and we argue that the entry for them into scientific inquiry did not depend on confronting and changing their initial views, but on tapping into their other ways of framing their activity. Their epistemological change primarily involved expanding on and stabilizing productive beginnings. As they experienced moments of sense making, including the participation and appreciation of the PD staff, it became easier for them to enter into that framing, in the context of the workshop.

In this chapter, we have focused our analyses on evidence of teachers' epistemological engagement *in situ,* with particular attention to what—and who—contributed to the stabilities of productive framings. We discussed how the PD staff played a significant role in the first summer, both to initiate and sustain moments of inquiry, and much less of those roles in the third summer. For this reason, we argued, the evidence showed progress in the teachers' stability in framing what was taking place as inquiry, stability we primarily attributed to the teachers as a group.

However, there are other dynamics at play in framing, and the stabilities may not be purely or even primarily epistemological. For this reason, we noted it may be more appropriate to speak of epistemological *aspects* of framing than of epistemological framing *per se.* That is, the structures of expectations shaping the teachers' framing in summer 1 likely formed from their previous experiences of science. But they formed as well from their experiences in schools more generally, experiences of high-stakes standardized tests, of lesson plans and supervisory visits and feedback, of the nature and purposes of professional development (Finkelstein, 2013).

Similar considerations apply to our analyses of summer 3, and we are cautious in making attributions of progress specifically with respect to teachers' epistemologies specifically. We have cited evidence of progress in three ways, for the rain group in summer 3.

First, most simply, there was much more of what we consider disciplinary engagement—of the teachers participating in ways we consider the beginnings of science. There had been only brief moments of this in summer 1; it was the general pattern in summer 3.

Second, more specifically, it was easier in the third summer for the teachers to enter this engagement. We understand this as happening for the same reason the teachers had an easy time framing what they were doing the first summer as thinking about instructional strategies, when the staff had other intentions: as they had experience framing things in this way, it became easier for them to do so again in the future. That is, experience gives rise to structures of expectations, which shape and are shaped by further experience.

Third, in summer 3 but not in summer 1, there was evidence of teachers as playing agentive roles in maintaining or restoring this framing of what they were doing. When one teacher began thinking in terms of instructional strategies, tapping into those structures of expectations, other teachers moved to restore the activity to their own sense making about phenomena. This suggests progress beyond the teachers having become more amenable to framing their activity in ways the staff promoted.

From this evidence, we have argued that one form of progress entailed teachers' becoming more stable in framings that they were able to enter only in moments from the outset, framings that included epistemological aspects productive for science.

We close with a proposal of a second form of progress. Above we noted the difference between finding epistemological *aspects* of the teachers' framing and a specifically epistemological structure of expectations. The former would explain the stability as involving conceptual, social, affective, and material aspects. The latter would attribute an epistemological abstraction from experience. For teachers, the two or three summers of experience in the workshops, connected to many more experience in everyday sense-making, may have supported their abstracting a sense of what "doing science" entails, an epistemological framing that could shape their experiences in still other contexts. We do not argue that the evidence we presented here supports this conclusion[3], but the considerations of this chapter point toward this as another form of progress to consider.

[3] There is evidence for a number of individual teachers of this form of progress, in shifts in approaches to science and science teaching beyond the workshops. Sharon Fargason, in fact, has written about her shifted views of science in a book about her teaching (Bresser & Fargason, 2013).

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## REFERENCES

Aguirre, J., & Speer, N. M. (1999). Examining the relationship between beliefs and goals in teacher practice. *Journal of Mathematical Behavior*, *18*(3), 327–356.

Belenky, M. F., Clinchy, B. M., Goldberger, N. R., & Tarule, J. M. (1986). *Women's ways of knowing: The development of self, voice, and mind* (p. 256). New York, NY: Basic Books.

Berland, L. K., & Hammer, D. (2012). Framing for scientific argumentation. *Journal of Research in Science Teaching*, *49*(1), 68–94.

Bresser, R., & Fargason, S. (2013). *Becoming scientists : Inquiry-based teaching in diverse classrooms, grades 3–5*. Portland, Maine: Stenhouse Publishers.

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. (2011). Expanding the dimensions of epistemic cognition: arguments from philosophy and psychology. *Educational Psychologist*, *46*(3), 141–167.

Conlin, L. D., Gupta, A., & Hammer, D. (2010). Framing and resource activation: Bridging the cognitive-situative divide using a dynamic unit of cognitive analysis. In S. Ohlsson & R. Catrambone (Eds.), *Proceedings of the 32nd Annual Conference of the Cognitive Science Society* (pp. 19–24). Austin, TX: Cognitive Science Society.

Elby, A., & Hammer, D. (2010). Epistemological resources and framing: A cognitive framework for helping teachers interpret and respond to their students' epistemologies. In L. D. Bendixen & F. C. Feucht (Eds.), *Personal Epistemology in the Classroom: Theory, Research, and Implications for Practice.* (pp. 409–434). Cambridge: Cambridge University Press.

Finkelstein, C. (2013). *Relational dynamics in teacher professional development*. University of Maryland, College Park.

Frank, B. W. (2009). The dynamics of variability in introductory physics students' thinking: Examples from kinematics. University of Maryland, College Park.

Frank, B. W., & Scherr, R. E. (2012). Interactional processes for stabilizing conceptual coherences in physics. *Physical Review Special Topics—Physics Education Research*, *8*(2), 020101.

Gillespie, C. (2013). Exploring the variability in how educators attend to science classroom interactions. College Park,MD: University of Maryland.

Goffman, E. (1974). *Frame Analysis: An essay on the organization of experience*. Cambridge, MA: Harvard University Press.

Hammer, D., & Elby, A. (2002). On the Form of a Personal Epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 169–190). Mahweh, NJ: Erlbaum.

Hammer, D., Elby, A., Scherr, R. E., & Redish, E. F. (2005). Resources, framing, and transfer. In J. Mestre (Ed.), *Transfer of learning: Research and perspectives*. Greenwich, CT: Information Age Publishing.

Hammer, D., Goldberg, F., & Fargason, S. (2012). Responsive teaching and the beginnings of energy in a third grade classroom. *Review of Science, Mathematics and ICT Education*, *6*(1), 51–72.

Hofer, B. K. (2010). Epistemological understanding as a metacognitive process: Thinking aloud during online searching. *Educational Psychologist*, *39*(1), 43–55.

Hofer, B. K, & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88–140.

Hutchison, P., & Hammer, D. (2009). Attending to student epistemological framing in a science classroom. *Science Education*, 1–19.

Jaber, L., & Hammer, D. (under review). Engaging in science: A feeling for the discipline.

Kuhn, D., & Weinstock, M. (2002). What is epistemological thinking and why does it matter? In Barbara K. Hofer & P. R. Pintrich (Eds.), *Personal epistemologies: The psychology of beliefs about knowledge and knowing* (pp. 121–144). Mahweh, NJ: Lawrence Erlbaum Associates.

Lau, M. (2010). *Understanding the dynamics of teacher attention: Case studies of how high school physics and physical science teachers attend to student ideas*. University of Maryland, College Park.

Lineback, J. E. (under review). The redirection: An indicator of how teachers respond to student thinking.

Lineback, J. E. (2012). *Mrs. Miller's evolution in teaching science as inquiry: A case study of a teacher's change in responsiveness.* University of California—San Diego & San Diego State University.

Louca, L., Elby, A., Hammer, D., & Kagey, T. (2004). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist*, *39*(1), 57–68.

Maskiewicz, A. C., & Winters, V. A. (2012). Understanding the co-construction of inquiry practices: A case study of a responsive teaching environment. *Journal of Research in Science Teaching*, *49*(4), 429–464.

McDermott, R., Gospodinoff, K., & Aron, J. (1978). Criteria for an ethnographically adequate description of concerted activities and their contexts. *Semiotica*, *24*(3–4), 245–276.

Perry, W. F. (1970). *Forms of intellectual and ethical development in the college years: A scheme.* New York, NY: Holt, Rinehart, and Winston.

Redish, E. F. (2004). A theoretical framework for physics education research : Modeling student thinking. In E. F. Redish, C. Tarsitani, & M. Vincentini (Eds.), *The proceedings of the Enrico Fermi Summer School in Physics, Course CLVI*. Bologna: Italian Physical Society.

Richards, J. (2013). *Exploring what stabilizes teachers' attention and responsiveness to the substance of students' scientific thinking in the classroom.* University of Maryland, College Park.

Rosenberg, S., Hammer, D., & Phelan, J. (2006). Multiple Epistemological Coherences in an Eighth-Grade Discussion of the Rock Cycle. *Journal of the Learning Sciences*, *15*(2), 261–292.

Russ, R. S., Lee, V. R., & Sherin, B. L. (2012). Framing in cognitive clinical interviews about intuitive science knowledge: Dynamic student understandings of the discourse interaction. *Science Education*, *96*(4), 573–599.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, *89*(4), 634–656.

Scherr, R., & Hammer, D. (2009). Student behavior and epistemological framing: Examples from collaborative active-learning activities in physics. *Cognition and Instruction*, *27*(2), 147–174.

Schommer, M. (1993). Epistemological development and academic performance among secondary students. *Journal of Educational Psychology*, *85*(3), 406–411.

Schraw, G., & Olafson, L. (2002). Teachers' epistemological world views and educational practices. *Issues in Education*, *8*(2), 99-148.

Tannen, D. (1993). What's in a frame? Surface evidence for underlying expectations. In D. Tannen (Ed.), *Framing in discourse* (pp. 14–56). New York, NY: Oxford University Press.

Tannen, D., & Wallat, C. (1993). Interactive frames and knowledge schemas in interaction: Examples from a medical examination/interview. In D. Tannen (Ed.), *Framing in discourse (pp. 57–76). New York, NY: Oxford University Press.*