Jaber, L. Z., Dini, V., & Hammer, D. (2022). "Well that's how the kids feel!"—Epistemic empathy as a driver of responsive teaching. *Journal of Research in Science Teaching*, *59*(2), 223-251.

"*Well that's how the kids feel!*" - Epistemic empathy as a driver of responsive teaching

Running head: EPISTEMIC EMPATHY AND RESPONSIVE TEACHING

Lama Z. Jaber[1], Vesal Dini[2], and David Hammer[2]

[1]Florida State University; School of Teacher Education

[2]Tufts University; Department of Physics and Astronomy & Department of Education

"*Well that's how the kids feel!*" - Epistemic empathy as a driver of responsive teaching

Abstract: While research shows that responsive teaching fosters students' disciplinary learning and equitable opportunities for participation, there is yet much to know about how teachers come to be responsive to their students' experiences in the science classroom. In this work, we set out to examine whether and how engaging teachers *as learners* in doing science may support responsive instructional practices. We draw on data from a year-long blended-online science professional development (PD) program that began with an emphasis on teachers' doing science and progressed to supporting their attention to their students' doing science. By analyzing videos from teachers' classrooms collected throughout the PD, we found that teachers became more stable in attending and responding to their students' thinking. In this article, we present evidence from teachers' reflections that this stability was supported by the teachers' intellectual and emotional experiences as learners. Specifically, we argue that engaging in extended scientific inquiry provided a basis for the teachers having *epistemic empathy* for their students—their tuning into and appreciating their students' *intellectual* and *emotional* experiences in science, which in turn supported teachers' responsiveness in the classroom.

Keywords: Scientific Inquiry; Science Teaching; Teacher Professional Development; Responsive Teaching; Epistemic Empathy.

1. Introduction

Researchers and educators are exploring how to engage students in science in ways that resonate with scientists' professional practice (National Research Council (NRC), 2012; Next Generation Science Standards (NGSS), 2013), where students learn science not simply as a collection of facts but rather as a pursuit of coherent explanatory accounts of phenomena (Engle & Conant, 2002; Ford, 2008; Ford & Forman, 2006; Hammer, Russ, Mikeska, & Scherr, 2008; Manz, 2015). This vision positions students as nascent scientists, sensemakers with a rich array of resources for learning. To realize this vision, teachers must take seriously students' ideas and experiences, including their everyday knowledge, questions, and curiosities, as they plan and teach their classes. We refer to this as *responsive teaching* (Robertson, Atkins, Levin, & Richards, 2016): teachers attending closely to their students' thinking and drawing on their interpretations of students' experiences to make in-the-moment instructional moves and adapt longer-term lesson plans. There is a significant array of research showing that responsive teaching can foster students' disciplinary learning and equitable opportunities for participation (e.g., Radoff, Robertson, Fargason, & Goldberg, 2018; Thompson, Hagenah, Kang, Stroupe, Braaten, Colley, & Windschitl, 2016; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001).

There has been less research, however, on how to support teachers to be responsive. Current efforts focus on engaging teachers in examining records of student thinking, such as in videos, transcripts, and written work, and on providing teachers first-hand experiences of doing science themselves (e.g., Atkins & Frank, 2016; Duckworth, 2006; Hammer & van Zee, 2006; Jaber, Dini, Hammer, & Danahy, 2018; Reiser, Michaels, Moon, et al., 2017; Salter & Atkins, 2013; Watkins, Coffey, Maskiewicz, & Hammer, 2017; Watkins, Jaber, & Dini, 2020). There is evidence the former— analysis of student thinking—can support teachers' responsiveness (e.g., Levin, Hammer, & Coffey, 2009; Geiger, Muir, & Lamb, 2016; Santagata & Taylor, 2018; Tekkumru-Kisa & Stein, 2015; Tekkumru-Kisa, Stein, & Ryan, 2018). However, there has been little direct study of how engaging teachers in doing science might influence their instructional practices. In this work, we set out to address this gap by examining a case in which engaging teachers as learners in extended science inquiry supported them to become, over time, more responsive in their practice as teachers.

Of course it is reasonable to expect that for teachers to engage their students in science as a pursuit, they need opportunities to experience that pursuit for themselves, to develop familiarity and comfort with it (Moon, Michaels & Reiser, 2012; Salter & Atkins, 2013; Watkins et al., 2017). Unfortunately however, studies continue to suggest that most teachers, especially at the elementary and middle school levels, have limited opportunities, if any, to experience science as a pursuit. Scholars therefore have called for more professional development (PD) programs to engage teachers in *doing science* (Banilower, Smith, Malzahn, Plumley, Gordon, & Hayes, 2018; Banilower, Smith, Weiss, Malzahn, Campbell, & Weis, 2013; Capps et al., 2012).

Accordingly, we designed a year-long blended-online science PD for upper elementary and middle school science teachers that began with an emphasis on their doing science. We engaged teachers in explorations of physical phenomena, drawing primarily on their own and each other's ideas and everyday experiences. Our goal was to design spaces for teachers where they can "mess about" (Hawkins, 1965) with physical phenomena, raise their own questions, conduct experiments to address those questions, and wrestle with uncertainty and setbacks in their explorations. In other work we explore how the teachers engaged in science within the PD (Dini, Jaber, & Danahy, 2019; Jaber et al., 2018); here we focus on how such engagement influenced teachers' instructional practices over time. More specifically, we set out to address the research question: *How did the teachers' instruction shift throughout a PD that engaged them in extended scientific inquiry?* Seeing evidence of their progress toward stability in responsive teaching, we continued to a second research question: *What about the experience of doing science supported the teachers' shift in their instruction?*

In what follows, we first review research that highlights the importance of responsive teaching for disciplinary learning, and then situate our work in larger efforts in teacher education aimed at promoting responsive teaching. Next, we discuss how we draw on the construct of *framing* to make sense of and design for teacher learning, describing the context of our project and outlining our analytical approach. We then present findings with regards to the two research questions.

We first provide evidence of teachers' progress toward responsive teaching, both in videos of their instruction and in their own reflections on their teaching practices. We then provide evidence that teachers' *epistemic empathy* contributed to teachers' responsiveness. More specifically, we argue that engaging in extended science inquiry supported the teachers' tuning into and appreciating their students' intellectual and emotional experience in constructing, communicating, and critiquing knowledge. By highlighting epistemic empathy as a driver for responsive teaching, our work contributes new insights that inform how teachers come to be responsive, insights that hold important implications for research and practice.

2. Responsive Teaching in Support of Disciplinary Learning

Recent science education reforms have emphasized the importance of engaging learners in disciplinary practices of science in order to make sense of the natural world (NGSS, 2013; NRC, 2012). This vision entails learners' "figuring things out" instead of simply "learning about" them (Schwarz, Passmore & Reiser, 2017). Classrooms, then, need to be transformed into spaces of knowledge building (Scardamalia & Bereiter, 2014) where learners act as epistemic agents who hold each other accountable to disciplinary norms and dispositions (Engle & Conant, 2002; Ford, 2008, 2015; Ford & Forman, 2006; Lehrer, 2009; Manz, 2015; Stroupe, 2014). "[W]hen the students themselves are actively critiquing each other," Forman and Ford (2014) explain, "they are supporting the emergence of disciplinary authority that occurs in science" (p. 201).

Transforming science classrooms into communities with epistemic agency and disciplinary authority requires a shift in teachers' practices, from providing and assessing knowledge to facilitating and orchestrating students' epistemic work. This entails becoming responsive to learners' own ideas and epistemic endeavors (Robertson et al., 2016). Rather than focusing on the established body of canonical knowledge as the exclusive goal, responsive teaching starts from and privileges student reasoning, while cultivating disciplinary practices of learning (Hammer, Goldberg, & Fargason, 2012).

Viewing learners as having a rich array of resources to explore, interrogate, and understand the world, responsive teachers make space for and elevate students' experiences, ideas, and curiosities (Coffey, Hammer, Levin, & Grant, 2011; Duckworth, 2001; Hammer, 1997; Hammer et al, 2012; Maskiewicz & Winters, 2012; Rosebery, Warren, & Tucker-Raymond, 2016; Windschitl, Thompson, Braaten, & Stroupe, 2012). Instead of evaluating them for alignment with the canon, teachers seek out the disciplinary roots in those experiences, ideas, and curiosities and build on the scientific beginnings in students' thinking and practices (Ball, 1993; Robertson & Richards, 2016; Russ, Coffey, Hammer, & Hutchison, 2009). Responsive teaching, then, grounds instruction in those beginnings in ways that honor student thinking and support them to make progress along disciplinary lines (Robertson & Richards, 2016).

Research indeed shows that responsive teaching can support disciplinary learning. For example, studies have shown that responsive teaching promotes students' conceptual gains and disciplinary practices (e.g., Coffey et al., 2011; Colley & Windschitl, 2016; Pierson, 2008; Radoff et al., 2018; Thompson et al., 2016). Moreover, by expecting value in student thinking and everyday experiences for scientific understanding, responsive teaching presumes that all students are capable meaning-makers (Robertson et al, 2016; Rosebery et al., 2016). It is an asset-based orientation that can foster equitable instruction, which is especially critical for under-represented students whose everyday cultural, emotional, and linguistic experiences are traditionally marginalized in science classrooms (Warren et al., 2001). Lastly, by centering instruction around student ideas and questions, responsive teachers open up curricula and classrooms in ways that position students as epistemic agents responsible for constructing, communicating, and assessing ideas (Duckworth, 2001; Ko & Krist, 2019; Ford, 2008; Scardamalia, 2002; Scardamalia & Bereiter, 2014; Sikorski, 2016). As such, responsive teaching promotes disciplinary learning and engagement by "bring[ing] students closer to the heart of what it means to do science" (Robertson & Richards, 2017, p. 317).

3. Teacher Education Efforts to Foster Responsive Teaching

A number of efforts have focused on supporting teachers to develop interpretive stances toward students' ideas and experiences (e.g., Hammer & van Zee, 2006; Levin & Richards, 2011; Tekkumru-Kisa & Stein, 2015; Rosebery et al., 2016). Using videos and transcripts as classroom artifacts, teacher educators have worked to hone teachers' attention to the substance of student thinking, to support them in making sense of and identifying the disciplinary beginnings in students' contributions, and to develop instructional responses that elevate and build on those beginnings (e.g., Levin, Hammer, Elby, & Coffey, 2012; Tekkumru-Kisa & Stein, 2015). There is evidence these efforts have resulted in teachers' increased attention to student thinking.

Teacher educators also expect that engaging teachers in doing science, with teacher educators and PD facilitators modeling responsive teaching (e.g., Dorph & Chi, 2013; Maskiewicz, 2016; Salter & Atkins, 2013), will help teachers take up similar practices. However, empirical accounts that document how such learning may translate into responsive teaching practices in the teachers' own classrooms is lacking.

In prior work, we have shown how by engaging in the doing of science, teachers make progress in their attention to each other's ideas, and more generally in their engagement and persistence in scientific explorations (e.g., Dini et al., 2019; Jaber, Hufnagel, & Radoff, 2020; Watkins et al., 2017). In the present study, we examine how teachers' engagement in extended science inquiry may shape their own instruction, especially in terms of their responsiveness to student thinking.

4. Framing as a Lens to Understand and Design for Teacher Learning

To make sense of teachers' engaging as science learners within the PD and as science teachers in the classroom, we draw on *framing* as a theoretical lens. Framing refers to participants' sense of what is going on in a particular situation (Goffman 1974; MacLachlan & Reid 1994; Tannen 1993). We reason that for teachers to frame *teaching science* as about engaging students in sensemaking, they need to be supported within PD contexts to frame their own *learning of science* in similar ways. Therefore, we argue that PD should be designed to foster a framing of "figuring things out", instead of simply "learning about" or "acquiring" knowledge from an authority, by engaging teachers as active learners and sensemakers (Passmore, 2014).

This notion is supported in educational research on student learning where framing has been used as a lens to examine how students interpret a learning situation and how such interpretations then shape their opportunities for learning (e.g., Berland & Hammer, 2012; Bing & Redish 2009; Elby & Hammer, 2010; González-Howard & McNeill; 2019; Hammer, Elby, Scherr, & Redish, 2005; Russ & Luna 2013; Scherr & Hammer 2009; Shim & Kim, 2018). For example, framing has been used to distinguish different ways in which students approach learning science, as an active process of sensemaking or as the application of formal knowledge acquired from an authority (Hammer et al., 2005, 2010; Hutchinson & Hammer, 2010; Redish, 2004; Jimenez-Aleixandre, Rodriguez, & Duschl 2000). Framing has also been used to study teacher attention and thinking about what is taking place in their classes (Levin et al., 2009; Richards, Elby, Luna, Robertson, Levin, & Nyeggen, 2020; Russ & Luna, 2013), as well as to understand how research subjects experience clinical interviews (Russ, Lee, & Sherin, 2012; Shaban & Wilkerson, 2019).

Across these accounts, framing is seen as an active, dynamic, and multilayered process. In framing a situation such as an activity in a science class or a PD program, participants draw on expectations from experiences, which may or may not align with the leaders' intentions. At the same time, framing is also dramatically influenced by contextual cues (e.g., Hutchison & Hammer, 2010; Rosenberg, Hammer, & Phelan, 2006; Shim & Kim, 2018). Thus a PD facilitator standing in the front of the room, projecting a PowerPoint presentation about some scientific concepts, or explaining a science demonstration, may reinforce prior expectations of science learning as about acquisition of facts and formal knowledge from an authority as typically experienced in delivery-mode lecture based science courses. If later the PD facilitator expresses curiosity about a question that a teacher has raised and invites others to work in small groups on that question, this invitation could cue a shift of framing, local to that moment. Participants' framing also depends on their sense of self, their social positioning with respect to one another, and the kinds of feelings experienced and recognized as legitimate (or not) within a particular situation (Ha & Kim, 2020; Shim & Kim, 2018; van de Sande & Greeno, 2012; Watkins, Hammer, Radoff, Jaber, & Phillips, 2018).

In other words, framing is a multilayered process involving not only epistemological but also identity, social, and affective dynamics that contribute to forming and maintaining one's sense of what is going on in a certain context. These complex and multifaceted dynamics all have roles in informing one's sense of how to participate and engage in an activity, and therefore are consequential for opening up and closing off opportunities for learning in any context, be it in the classroom or in a PD setting. With these considerations in mind, we approached our PD work with the teachers with an eye toward how our actions and positionalities, and how teachers' prior science learning and teaching experiences, could shape teachers' opportunities for learning. Below, we discuss the context of the project elaborating on how framing informed our interactions with the teachers throughout the PD.

5. Methods

5.1. Context

The context for this exploratory study is a three-course science professional development (PD) program for upper elementary and middle school teachers that spanned from August to June. Teachers collected videos from their classes throughout the PD, which provides a corpus of data for this study. All three courses considered both teachers' own inquiries in science and their students, but with different levels of emphasis. The first course in the series centered on teachers' own engagement in scientific inquiry; the second had teachers study video examples of student inquiry in addition to engaging in their own inquiry with roughly equal emphasis, and the third focused primarily on teachers' analyses of student thinking as evident in their videos. Eight teachers from three high-needs school districts with varying years of teaching experience (ranging from 3 to 26 years) and with diverse academic backgrounds completed all three courses (see Supplementary Material 1 for more information about participating teachers). The teachers and the PD facilitators met in-person once per month as a large group, and for the rest of the time, they interacted online in a discussion-board learning environment that allowed them to post text, attach documents, and upload images and videos.

5.2. Pedagogical Approach

We designed the PD to engage teachers in doing science as a "refinement of everyday thinking" (Einstein, 1936, p. 59), starting from their everyday ideas and ways of thinking, and refining from there through experiments and theoretical discussion toward coherent, mechanistic accounts of natural phenomena. By providing teachers varied opportunities to experience science as a pursuit of understanding, our hope was that they come to frame teaching as about providing similar opportunities for their students.

Therefore, throughout the PD, we engaged teachers in extended science inquiry where they relied primarily on their own efforts to make sense of phenomena. To those ends, our science explorations generally began with a launching question (e.g., Why does a helium balloon float?; How does a siphon work?; Does an ice cube melt faster in a cup of freshwater or saltwater at the same temperature?). That question, we expected, would generate other questions: its main role was to "launch" inquiry, with the teachers as the principal epistemic agents. The explorations lasted from 3 weeks (for the first one) to 8 weeks (later in the PD). During those science explorations, we encouraged teachers to start from their everyday experiences and intuitions, and with them, we co-created what we called a "mini-scientific community," a phrase we frequently used to emphasize the commitment to collective knowledge construction. Part of this entailed the community developing practice and expectations—stabilities of framing—which we took as key objectives.

We anticipated that the teachers' prior expectations about PD, their expectations of what it means to teach and learn science, and their own facility and comfort with science, could all shape how they framed the PD and their own learning within it. With these considerations in mind, we sought to practice and model responsive teaching, including to elicit, make sense of, and pursue teachers' own ideas, curiosities, and lines of reasoning, both during our face-to-face interactions and online (for additional details regarding PD design and enactment, see Jaber et al., 2018 and Watkins et al., 2020). This motivated our use of "launching questions": Rather than moving along a predetermined pathway toward particular canonical understandings, we attended closely to teachers' explorations and sensemaking efforts and chose next moves in response to those efforts. Week-to-week, we worked to form a sense of the teachers' thinking and to identify productive threads to advance both individual and collective inquiry. From there, we designed prompts and learning activities for the following week that built on teachers' contributions.

In responding to teachers' weekly posts, we provided individualized feedback, to elicit their ideas, encourage them to explain and justify their thinking, and push them away from memorized knowledge. We also urged the teachers to rely on each other's thinking and investigations to address their emergent questions instead of consulting external sources. Thus we oriented them to one another's posts, pointing out alternative arguments or inconsistencies in the community, or inviting them to consider their peers' experimental results. Additionally, we provided the teachers access to our *Instructors' Notes* document where we synthesized the group's thinking to foreground common themes and questions, as well as emergent consensus ideas across explanations.

Lastly, we attended and responded to their affective experiences, such as by validating their sense of vexation when they felt stuck or by sharing their excitement for an interesting experimental result. We affirmed that vexation and struggle are not only to be expected but essential. We also explicitly discussed how the experience of uncertainty and frustration at not knowing could be channeled in ways that support scientific pursuits in anticipation of the pleasurable feeling of figuring something out. These discussions, we reasoned, would help teachers frame moments of discomfort as a necessary and perhaps even an exciting part of doing science. In these various ways, we communicated that we deeply cared about teachers' sensemaking and that we privileged their epistemic work more than their arrival at predetermined answers, a goal we hoped they would eventually take on in their classrooms with their own students.

5.3. Data Sources

In order to examine how teachers' instructional practices shifted throughout the PD, our primary source of data consisted of videos from participating teachers' classrooms. From this dataset, we focused on four videos per course for each teacher collected every 3 to 4 weeks (for a total of 12 videos per participant, averaging 17 minutes per video). Our goal was to represent a chronological snapshot of teachers' instruction over the duration of the PD.

To understand what may have supported the shifts in teachers' instruction, we drew on teachers' interviews conducted by a researcher unaffiliated with the course and on final papers where the teachers reflected on their experiences in the PD. The interviews and final reflections also helped us attend to shifts in how teachers framed the work of teaching in ways that corroborated and extended our analysis of the classroom videos. Below, we describe our analytical approach to the video data followed by a description of our analysis of teachers' interviews and reflection papers.

5.4. Analytical Approach

5.4.1. Analyzing videos from teachers' classrooms

To address our first research question, "*How did the teachers' instruction shift throughout a PD that engaged them in extended scientific inquiry?"* we first analyzed teachers' classroom videos that were collected throughout the PD (Derry et al., 2010). The first and second authors watched all the videos and outlined general observations for every teacher. We selected five minutes of each video, from minutes 2 to 7, as we noticed that for most videos the first two minutes were generally dedicated to establishing order and setting up norms.

In our first pass, we wrote extensive notes to characterize teachers' instructional moves either as traditional, teacher-centered, or as aligned with responsive teaching. The former included the teacher presenting information or engaging in Initiate-Respond-Evaluate (IRE) patterns of interactions (Mehan, 1979). The latter, indicators of responsive teaching, included the teacher eliciting, revoicing, and elevating student ideas, checking for their understanding of student thinking, encouraging students to draw on everyday experiences, and juxtaposing student arguments to invite the class to debate them. While we drew on patterns from the literature to characterize teachers' instruction, we were also attentive to what emerged in the data. For example, we noticed that in early videos, one teacher relied on songs to help her students memorize technical vocabulary and definitions. Another teacher used role play where he invited a guest teacher to embody the persona of a scientist who presented information to students and answered questions. We took note of these observations as part of characterizing and depicting teachers' instructional practices throughout the PD.

As we examined the data, we became excited about the later videos where we saw clear evidence of the teachers eliciting student thinking while paying close attention to the substance of that thinking and taking it up in their next instructional moves. We also noticed that as teachers oriented to and took up student thinking as scientific, students started to engage in similar ways with each other's ideas and lines of reasoning. In some cases, the students took the lead in probing and pressing each other, asking for evidence to justify claims, and building upon each other's ideas. In other words, instead of relying on the teacher to orchestrate collective sensemaking, the students took on that role. To us, this indicated shifts in the classroom norms and instructional practices, shifts that reflected the development of an epistemic community centered on the collective development and refinement of ideas (Scardamalia & Bereiter, 2014).

Therefore, in the next round of analysis, we specifically examined the video transcripts for evidence of whether and how the teachers took up and responded to students' ideas as scientific—noticing student thinking, elevating the substance of that thinking, and working to explore and advance it. As summarized in Table 1, evidence that we considered reflective of teachers' responsiveness included: revoicing a student idea with interpretation; expanding the substance of student ideas; probing with reference to specific student ideas and not necessarily for the purpose of leading to the canon; engaging student ideas by considering their plausibility and coherence within the student's own line of reasoning; making connections among student ideas; and making specific requests for meaning at a meta level. These actions, which we took to signal teachers framing of their role as about closely attending and responding to student thinking, helped us characterize shifts in teachers' interactions with their students over time.

Using teachers' turns of talk as our primary unit of analysis, we applied our descriptions of evidence in Table 1 to examine the video transcripts. A talk turn could include zero, one or more than one instance of responsiveness. For example, a teacher heard and responded to students' wondering why lightning often precedes rain but not always. In response, the teacher asked:

> I don't know, I need to hear more about this. Why, why do we have lightning sometimes and sometimes we don't? What's the difference? How does it form? Why does it happen? Abbigail what do you think?

Though this turn of talk comprises a series of five probing questions, they all respond to the same question. We therefore considered this turn of talk as one instance of responsiveness that reflects the teacher's uptake of students' wonderment about lightning and rain, including her effort to guide them to consider mechanism ("How does it form") and to elicit their ideas.

For another example, from another class, the teacher heard students debating whether adding more weight to an object would make it sink, bringing in examples such as filling a bottle with sand or filling a balloon with water. A student, Mike, argued that a water balloon would actually float in a pool but sink in the ocean due to the waves, noting that the "ocean is stronger than the pool." In response, the teacher first inquired about what the student meant by "stronger." Then in her next turn of talk, she first revoiced the student's idea to make sure she understood it and others heard it, by saying:

> So the force of the waves is now coming into play because, that's determining whether something is going to sink or float? That's what you just said. Didn't, isn't that what you

just said? Okay, I'm I'm just, I want you to clarify. I'm not saying yes that's right, no that's wrong. So now we've got an interesting conversation. We are talking about force, you were talking about adding weight, well sand in the bottle or balloon with water. You, you guys talked about adding more weight to things and that's gonna cause it to sink. Emily, what do you think?"

We see this long turn of talk as comprising two instances of responsiveness: the first one in the teacher's clarifying Mike's wave idea, and the second in her follow-up to the weight idea that the students have been debating for a while. The teacher then invites students to consider and discuss these two factors and their impact on floating and sinking.

Table 1. Evidence of teachers' responsiveness to the disciplinary substance of student thinking.

Evidence	Examples
Revoicing an idea with interpretation (instead of simply repeating students' words).	So, your thought is that, and correct me if I'm wrong, there's oxygen down here because the balloon is filled with helium. Helium is lighter than oxygen, and it allows the balloon to rise because the oxygen is heavier so it goes below it?
Expanding the substance of student ideas, such as by bringing in an example to illustrate an idea or seeking and providing evidence to support it.	Why does the water in the cup- we know that sunshine heats it up, but how does it go from water in the cup? Like I heat- I heat up my coffee every morning and the coffee is still in the cup. It's, it's not all gone.
Probing with reference to specific student ideas (and not necessarily for the purpose of leading to canon).	if you don't mind I'm gonna push you a little bit here, it's a really interesting thought.... but when you talk about a low point of a river or lake or something, you're talking about an area that's physically lower than another point, right?....So you're saying that those water molecules are going to find a way down to the lowest point of the cloud?
Engaging student ideas by considering their plausibility and coherence within the student's own line of reasoning (and not necessarily for the purpose of correcting or leading to the cannon).	Global warming. I'm still wondering about- Is it, did you say that Jared? If the heat gets stuck going out, why doesn't it get stuck coming in? What stops that from happening?... So if the carbon blocks it to go out, how come it doesn't block it to come in?

Making connections among student ideas, such as juxtaposing, comparing, and noticing inconsistencies among ideas.	So you have two lines of thinking, one it will end at the end of the atmosphere, the other is it would just keep going out into space.
Making specific requests for meaning at a meta level, such as inviting students to defend positions about specific ideas or explicitly inviting students to assess claims for coherence and plausibility.	What do you think, and I'm going to open this up to everybody, I don't want you to think I'm sitting here grilling you. But I'm really intrigued by it though. So what umm what would cause those water molecules that are in a gas state, once they're up in the cloud, what's actually going to cause them to move from just every other part of the cloud down to that low point, if that's the case, what do you think?

As we identified instances of teachers' responsiveness, we encountered borderline cases. These included moments where teachers pressed students to explain their thinking, such as by generically asking "why" without including the student's idea in their question. We chose not to consider these as evidence of responsiveness. While such instances show the teacher probing a student's thinking, they do not provide evidence that the teacher is attending to and engaging the substance of that thinking. In other words, in such instances, it is unclear whether the "why" is simply used as a talk move to keep the discussion going or whether the teacher has interpreted the substance of student thinking and is wanting to follow up on the idea by asking for the reasoning behind it. It was only when there was clear evidence of attention, for example the teacher asking, "why do you think that the helium would escape from the balloon?", that we considered the instance as evidence of responsiveness.

Another tension came up when teachers elicited student thinking, and a few turns later, it became clear that the elicitation was in service of getting students closer to a canonical idea or lesson objective, instead of taking up students' own lines of reasoning and exploring *their* meanings more deeply. For example, consider this moment from Rachel's third video where students were observing how peeled and unpeeled grapes behave when placed in a cup of soda. Sammy had just shared his hypothesis that the green (unpeeled) grape will start to fizz and

Derrick followed up by saying that the green grape is "dissolving." Rachel asked Derrick to clarify what he means by "dissolving:"

Sammy: My hypothesis is, um, it would start to fizz.

Rachel: Okay, so what else can you tell me? What are some things that you're seeing happen?

Derick: It's, the green is dissolving. And the red one is…

Rachel: So what does that mean, "dissolving"? What does dissolving mean though?

Sammy: Like disintegrating in the liquid.

Derick: the different particles are just coming-

Rachel (interrupting Derick): So are you sure that's the right term, is that what you see happening?

Sammy: No, it's kind of like, letting out like, I think, air or something?

One could think of Rachel's question around the meaning of "dissolving" as an example of her responsiveness to students' thinking and her willingness to pursue their lines of reasoning. However in her next turn, instead of exploring the responses of the grape "disintegrating in the liquid" and "different particles are just coming," Rachel interrupted the students to question their choice of the term "dissolving," effectively challenging the correctness of his thinking rather than helping him to articulate it. (That apparently led Sammy to drop his idea and propose another, in a hedging tone: "No, it's kind of like, letting out like, I think, air or something?") As such, while at first glance Rachel's question around "dissolving" may be seen as an instance of responsiveness to student thinking, in considering the broader context within which the instance was situated, we interpreted her to be more focused in that moment on correct terminology than in exploring student thinking. Thus we did not consider this turn of talk as evidence of responsiveness.

5.4.2. Analyzing teachers' interviews and final papers

While the video data allowed us to document shifts in teachers' instruction in their own classrooms, we drew on data from teachers' reflections in interviews and in their final papers to examine whether and how teachers themselves identified changes in their instructional practices. This additional dataset was particularly useful to characterize shifts in how teachers framed the work of teaching and to identify aspects of the PD experiences that teachers described as consequential for shifting their practice, helping us address our second question.

The interviews were conducted by a researcher unaffiliated with the PD who asked teachers to reflect on their experiences in the program, ways in which it influenced their instruction, suggestions for improvements, and other questions (see Supplementary Material 2). In addition to these interviews, teachers responded to the following prompt in their final reflection papers:

> *Thinking back over the year, what, if anything, has changed in how you think about science and science teaching? (We wondered if it would help to go back and watch your first video from the fall, but that's totally up to you.)*

The first and second authors examined the data independently, identifying relevant excerpts that 1) reflected teachers noticing shifts in their instruction and 2) highlighted key aspects of the PD that teachers described as challenging or productive for such shifts. We each annotated and characterized the identified data excerpts using descriptive coding (Saldaña, 2015). We met to discuss our findings and then subjected the data and our interpretations of it to critique by research colleagues at our respective institutions.

These rounds of analysis and extensive discussions around the data allowed us to identify a common thread across all teachers' interviews and final reflections: teachers tapped into their own experiences of doing science as a means to connect to their students' epistemic experiences, what we refer to as "epistemic empathy." For example, teachers drew on their experiencing emotions in their own inquiries, such as feeling excited when at the edge of figuring something out or feeling vexed when wrestling with uncertainty, to understand their students' feelings in the classroom. They drew on their learning from one another within a "mini-scientific community" and overcoming challenges together as they reflected on the learning opportunities they hoped to provide their students. As we explain in the findings and discussion sections, these insights helped us conceptualize epistemic empathy as an important and overlooked aspect of teacher learning.

To document evidence of teachers' epistemic empathy, we re-examined teachers' interviews and written reflections to find instances where teachers made explicit links between their experiences as learners in the PD and their students' experiences in the classrooms. Those included:

- instances where teachers reflected on how their engagement in science allowed them to better interpret and make sense of their own students' experiences (e.g., "As I reflect now, I think [students] were just going through the first phase I went through"; "they [my students] may have had the same kind of issues [that we had]"; "they transformed our thinking into the thinking of the kids");
- instances where teachers commented on how doing science helped them reframe their goals for their students' learning (e.g., "I need to help [my students] see what

each other is thinking just as I experienced [doing science with my peers in the PD]"); and

- instances where teachers commented on through engaging in science, they gained a deeper appreciation of their students' feelings and experiences in the science classroom (e.g., "by being dropped into the middle of what our students feel when they begin classes gave us a unique perspective"; "Just as I saw in each of us, I know I will see my new students opening up to this idea of thinking and doing science").

We consider all of these markers as evidence of teachers' tuning into and valuing learners' intellectual and emotional experiences in science, that is, of teachers' having and expressing epistemic empathy for their students. By supporting teachers to notice and appreciate their students' experiences, epistemic empathy, we argue, helped them reframe their roles as science teachers—from helping students learn the canon to engaging them in meaningful sensemaking opportunities similar to those the teachers experienced in the PD.

5.5. Researchers' Positioning

The first and second authors were the PD instructors for the first two courses in the series, working closely with their supervisor, the third author. The second and third authors were the instructors of the third course. Our varying levels of engagement in teaching the courses allowed for a unique continuum of insider and outsider lenses that enriched our understanding and interpretations of the data. To avoid any potential conflict in terms of our positions as PD course instructors and researchers, we did not engage in data analysis while teaching the courses. During the various stages of the analysis, the first and second authors engaged in all aforementioned analytical steps, analyzing videos, interviews, and reflection paper data. They first examined the data independently and they met throughout the various stages of the data analysis process to compare their interpretations and resolve disagreements. They consulted with the third author at different stages, consultations that allowed the group to converge on shared meanings and to continuously revise and refine our understanding of the data.

6. Findings

The findings are organized in two main parts. The first part, *Progress in Responsive Teaching*, addresses the first research question by depicting initial patterns in teachers' instructional practices and shifts in those practices using evidence from both classroom videos and teachers' reflections. The second part, *Epistemic Empathy as Stabilizing and Supporting Responsive Teaching*, addresses the second research question by highlighting the role of empathy, specifically *epistemic* empathy, in teachers' progress toward responsive instruction. This second part draws on evidence from teachers' reflections in their interviews and in their final papers.

6.1. Progress in Responsive Teaching

In this section, we first describe patterns in teachers' instruction near the beginning of the PD using evidence from video recordings of teachers' classrooms. We then discuss teachers' progress toward responsive teaching over the course of the program as evident in classroom videos collected throughout the PD. Lastly, we examine teachers' interviews and final papers for evidence of how they described and framed shifts in their instructional practices.

6.1.1. Initial patterns of instruction

Near the beginning of the PD, the video recordings from teachers' classrooms showed delivery-pedagogy (Stroupe, 2016). The discussions exhibited the characteristics of teacher-centered classrooms, with teachers having longer turns of talk and with many more teacher-to-student rather than student-to-student interactions. To provide a window into the initial videos, we present three typical excerpts from three different teachers' classrooms.

The first excerpt, from Dione's third video, shows a very common interaction pattern, the Initiate-Respond-Evaluate (or IRE) sequence (Mehan, 1979; Sinclair & Coulthard, 1975), where teachers initiate a question, wait for students to respond, and evaluate those responses for their correctness:

Dione: Does everybody know what this [referring to H_2O] means?

Multiple students: Yes, water.

Dione: I know you know it means water cause I just said water and wrote that, but what's H2O mean?

Erin: It's how you describe the molecule of water.

Dione: The molecules, does anybody know what it contains?

Sarah: Hydrogen and oxygen

Dione: Hydrogen and oxyg- oxygen, does anybody know what the 2 means? Yeah?

Mike: Two percent of hydrogens.

Dione: Not percent, close though.

Mike: 2 molecules

Dione: Two mole- two atoms, and one atom of oxygen and they come together to make the molecule. Good.

As evident in this excerpt, Dione drives much of the conversation by asking questions with the purpose of guiding her students toward the correct canonical ideas. When the students' answers do not match her expectations (e.g., "Not percent, close though"), she offers a correction ("two atoms, and one atom of oxygen and they come together to make the molecule").

Another feature common among these early classroom discussions was a focus on key scientific terminology, as in the following excerpt from Gabriel's first video:

Robert: The fossils that are found in South America and in Africa. They- um, because like the Mesosaurus wasn't able to travel across the Atlantic Ocean, so they must have been walking on land to a different area. Or populated in a different area many many many years ago.

Gabriel: Good.

Robert: Or in the continental drift.

Gabriel: So guys, what was a key word you just heard Robert just then say?

To help her students memorize vocabulary terms and facts, another teacher, Jessica, used songs. The following excerpt is taken from her first video right after her students had listened to a song about heat transfer and then filled out worksheets related to the content of the song. Jessica elicited students' answers to the questions on the worksheet by asking:

Jessica: On this song, heat energy can be transferred in how many different ways? Elena?

Elena: Three

Jessica: Three, awesome, three different ways. [...]

Jessica: What does it move from and to. We talked a little bit about this a couple days ago, Amber?

Amber: Heat moves umm from where it comes from to cooler

Jessica: To cooler, it always goes from the warmer to the cooler, excellent. Good, so from warm to cold. In the song they actually said from hot to frozen I think were their words. But they- but the idea is to go from warmer to cooler, warmer to colder. And don't you worry, I'll have that stuck in your head through another song by the end of today.

These exchanges reflect the teachers' goal to help their students reproduce the canon, a goal that was prevalent in the initial videos. As such, the teachers viewed their role as mainly to convey information, assess students' ideas for correctness, and provide resources such as textbooks or songs that help students access and memorize scientific facts.

6.1.2. Evidence of shift in teaching from classroom videos

It is not surprising, in light of the examples above, that when we analyzed teachers' initial classroom videos for evidence of responsive teaching, the videos showed little evidence of responsiveness. However, over the three-course PD, we saw changes in teachers' instructional practices. More specifically, the evidence showed that the teachers became more responsive to the substance of student thinking in the videos they submitted during the second and third courses as compared to the first, as illustrated in figures 1 and 2. Figure 1 shows an increase in the total instances of responsiveness across all participating teachers over the three courses; Figure 2 shows the number of instances for each participating teacher in each course and indicates increased responsiveness in *all* of the teachers' classrooms in the second and third courses. We argue that the evidence of shifts in instructional practices reflects a shift in how teachers framed the task of instruction, from a focus on delivering canonical knowledge toward privileging students' own engagement in inquiry and in reasoning about phenomena.

Figure 1. Total instances of responsiveness to student thinking over the three-course PD.

Figure 2. Total instances of responsiveness from each teacher's classroom over the three-course PD.

To provide a tangible example of the shift in teachers' instruction, we present an extended episode from the eleventh video of Kim's fifth grade classroom, an episode representative of many of the interactions characterizing teachers' later videos. We purposefully highlight Kim here because, as can be seen in Figure 2, her early videos showed the least evidence of responsive teaching. In this episode, Kim asked her students to explain why "some objects can float in ocean water while others can't." Students offered different explanations for floating objects including the presence of air and the weight of the object. The first part of the conversation represents student-to-student talk, where they took up each other's ideas, debated the merits of the ideas, and pressed each other to examine and revise their claims. After a student, Candice, argued that air in the object makes it float, another student Laura responded:

Laura: Umm, I say, I think it doesn't have to do with whether or not there's air in the object because if you have like certain types of metals- Like certain metals will float in the ocean compared to other metals. And so I think it all depends on how light something is, other than like the amount of air it contains, I mean it can't like, like pumice I guess, well yeah I guess I agree with you, but like other like things like yeah, I think she's- wait, can you clear up what you were trying to- like all objects have to contain air in order to float in water, is that what you were saying?

Candice: Well I was saying that like, pumice would, like you were saying, pumice, pumice would float because I think it has- isn't pumice the one that has like the holes?

Multiple students: Yeah, like air sockets.

Candice: Yeah, and it has air sockets.

Laura: Yeah okay so, like are you trying to say like that all objects have to take in air in order to float?

Candice: Umm, yeah

Laura: Oh, I I disagree with that. I- but I think that it can contain air but I think that like, I don't know, yeah. Like I was saying before, like it can contain air to make it lighter, but I think it has to like be lighter.

The teacher, Kim, interjected after a few turns, as a facilitator and co-explorer of the phenomenon, asking questions, revoicing ideas, and wondering about the science herself:

Kim: So it depends on what the- what material it is?

Laura: Like the amount of mass or

Kim: The amount of mass.

Laura: Yeah, of the object's, well, yeah, or the material it's made of. Cause like sand doesn't float in the ocean but it, like if you took some air- some sand and you put it in a bottle, it would sink but there's still air in it.

Kim: I wonder if you filled up a bottle with sand, would that float?

Laura: No, I think it would sink [...]

Mathew: Umm, well, it will sink, Laura is right, it would sink. It would sink because of- it has more weight instead of air because air is, has no weight. [...]

Adele: I disagree with Mathew because I had full water balloons and I put them in the pool and they would bob. Cause of the weight, so I think that if you didn't fill it up all the way it would halfway sink and like the top would float up.

Kim: So you filled up balloons with some water, were they completely filled?

Adele: Sort of, they were

Kim: And then you put them in the- your pool,

Adele: But they wouldn't go down [...]

Attending to Mathew signaling his disagreement, Kim reoriented the discussion to him:

Kim: And Mathew is saying no, so you think a balloon filled with water is going to sink in the ocean?

Mathew: Well, the ocean- is the ocean is stronger than the pool.

Kim: What do you mean stronger than?

Mathew: Umm, the pool doesn't have waves in it. While the umm- well the ocean has waves, has waves so that's how the balloon could sink. [...]

In a move likely intended to make sure that all students were following along, and perhaps to invite other voices to the discussion, Kim summarized the two examples that students provided to either support or challenge the argument that adding weight will make an object sink:

Kim: Okay, so now we've got an interesting conversation. We were talking about, well sand in the bottle or balloon with water. You, you guys talked about adding more weight to things and that's gonna cause it to sink. Emily, what do you think?

The episode shows Kim and her students actively attending to and pursuing one another's ideas. The students contributed most of the substance (e.g., proposing why things float including airiness or weight); they closely listened to and probed each other's thinking (e.g., Laura asked Candice "is that what you were saying?") drawing on everyday experiences to either support or challenge claims (e.g., Adele drew on her experience of seeing a water balloon float in a pool to challenge Mathew's idea that if something is heavy, it cannot float). The teacher in the meantime paid close attention to how the conversation was unfolding, and interjected at different times to elicit student thinking ("I wonder if you filled up a bottle with sand, would that float?"), to check for her understanding of their ideas (e.g., “What do you mean stronger than?”), and to bring the class together by connecting across ideas and inviting other students to consider them (e.g., “We were talking about, well sand in the bottle or balloon with water. You, you guys talked about adding more weight to things and that's gonna cause it to sink. Emily, what do you think?”).

Comparing these interactions with those at the beginning of the PD, there is a clear shift in the classroom norms and conversational patterns, reflecting a shift in how Kim framed her role in the classroom. Kim became more intentional about making space for students’ voices, prompting them to clarify their ideas, and encouraging them to interact with each other’s thinking. Kim enacted practices of responsive teaching that signaled to us as analysts as well as to her students that her primary attention was on their thinking and that she was taking their ideas and questions seriously.

While this example illustrates responsiveness within one lesson, toward the end of the PD, some teachers started to pursue students’ ideas and questions over multiple class sessions or weeks in a row. This kind of responsiveness shows teachers’ willingness to engage their students in extended inquiry around a science question in ways that resembled their own explorations of a single phenomenon for multiple weeks within the PD. Opening up their classrooms as spaces for student inquiry indicates a shift in how the teachers framed teaching: from supporting students to memorize facts and learn scientific terminology to facilitating students’ sensemaking, positioning them as epistemic agents (Miller, Manz, Russ, Stroupe, & Berland, 2018; Scardamalia, 2000; Stroupe, 2014).

6.1.3. Evidence of shift in teaching from teachers’ reflections

In addition to the evidence from the videos, the teachers described shifts in how they approached the task of instruction in their interviews and final reflection papers. Consistent with our video analysis, this additional dataset shows that *all* teachers noticed a change in their instruction, most prominently in their facility with listening and responding to student thinking. Additionally, this data indicate a clear shift in how teachers framed their roles as teachers and what they hoped for their students to experience in the science classroom. Below, we illustrate these findings with representative quotes from the teachers' interviews and final papers.

Teachers noted how their ways of teaching at the beginning of the PD were in stark contrast to responsive teaching. Kim, for example, wrote:

> I started the beginning of the year the same way I always had, teach the curriculum using the materials provided by the district and don't stray away from that. As I continued throughout this course I inched my way toward a different approach..[...] I now create questions that evoke thinking and problem solving that ultimately allows my students thinking to take the forefront, not my well-constructed lesson plans. The students' thinking is now in the driver's seat.

Kim described her shift from a traditional teaching approach centered on delivering "well-constructed lesson plans," to "a different approach" that privileges student thinking. Jessica wrote about a similar shift in her orientation to student thinking and her role as a science teacher, moving away from teaching as about conveying facts to facilitating the doing of science:

> Prior to these classes, I taught Science in a very traditional way: Here's the topic, new vocabulary to use, practice with new concepts, apply new concepts, test and move on. [...] I don't think that my job as a Science teacher is to teach facts about Science anymore. I now think that my job as a Science teacher is to teach students how to: observe the world around them; question it and how or why it works; hypothesize and then test ideas; problem solve and analyze when things don't go as expected; share and listen to findings

with others; be reflective; and have stamina to focus on a topic until you have a deep understanding.

Teachers described their increased facility with listening to students' ideas and orchestrating discussions to build on those ideas. Gabriel wrote:

> My thoughts and approaches to how I conduct conversations in my classroom have progressed a great deal. [...] Even as I first tried to let them guide the conversation a few videos into the courses, the students could still tell by my tone that I was driving at something and too many students read this correctly and stopped taking chances with what they thought and waited for someone with the "right answer" to speak up. It was not until almost the very end that I "pulled it much more together".

Carlos similarly talked in his interview about his developing comfort in attending and responding to student thinking:

> I feel *far* more comfortable listening to student ideas, seeking clarification, and analyzing them for meaning than I did even several short weeks ago. I also feel far more comfortable with my classes all being at different points in their discussions and investigations than I previously was.

After watching her initial videos from the Fall semester, Kayla wrote of her learning to listen carefully to the substance of student ideas and commented on the subsequent change in her classroom dynamics:

> I feel that one of the biggest areas that I have seen progress in is my ability to listen, and try to understand what students are saying. I feel that this alone has led to much better discussion in my classroom. I have been working on carefully listening to what the students are saying and asking questions of them to further their thinking and explaining.

> My modeling of this behavior, and showing an actual interest in what the students are saying has rubbed off and I now see students doing the same thing. They are asking their peers to further explain their ideas when they do not understand something and questioning their peers when there are inconsistencies in what they are saying. I have found that when students are asked to further explain their thinking, or explain an inconsistency they gain a better understanding and are learning to problem solve and reason with their ideas. In addition, students have learned to listen to each other and are truly trying to understand what the other students are saying. Furthermore, having this open dialogue in my classroom has facilitated an environment where the students are eager to engage in deep thoughtful conversations and genuinely interested in what their peers are saying.

Indeed, all teachers commented on shifting to foster student agency and engagement in science. Peter wrote: “I have learned what is really important for my students and that it is not just ‘canon’ but the reasoning, evidence gathering, and collaborating that occurs around it”. Along those lines, Jessica noted: “When our students can do these things, they will have access to any and all science facts when they want them. Without these skills, our students will continue to try to memorize facts that don't have meaning or value for them. Which means, it won't last in memory.”

Dione expressed a “renewed sense of responsibility” to engage her own students in doing science by listening closely and being responsive to their thinking, noting:

> After taking these classes, I feel a renewed sense of responsibility to incorporate that basic idea of teaching into listening to my students as they think about concepts [...] To look back at where I was in September compared to now, I can see a change - I am no

longer the "old-school"-veteran teacher who will open yet another school year the same way I have for the last 25 years. I feel like I have a bigger job to do. Not only do I owe it to my students to create life-long thinkers, but I owe it to myself to make sure I am giving the students a strategy to take life by the horns and think!

In sum, as the PD progressed, teachers' own reflections as well as their videos of instruction show that they framed and implemented science instruction differently, expressing excitement for the outcomes of and possibilities in responsive teaching.

6.2. Epistemic Empathy as Stabilizing and Supporting Responsive Teaching

In order to understand what supported teachers' shift in instruction toward more responsive practices, we examined teacher interviews and final reflection papers for aspects of the PD experiences that the teachers identified as particularly powerful for their learning. Our analysis converged on an emergent theme salient across all the data, that of *epistemic empathy*—the teachers' tuning into and appreciating another's cognitive and emotional experiences in constructing, communicating, and critiquing knowledge. This points to a distinct benefit of teachers' engagement in their own extended scientific inquiries: Their experience of the intellectual and emotional work of doing science supported their empathy for students.

We propose that there are two levels in which epistemic empathy supported responsive teaching. First, it helped teachers recognize more in their students' thinking and experience in particular moments: having had first-hand experience with the practices and feelings of science, the teachers more readily recognized such practices and feelings in their students. Second, by supporting teachers to notice and appreciate their students' experiences at a deeper level, epistemic empathy helped stabilize teachers framing their classes as about students' doing science, including their experience of epistemic feelings that arise during inquiry. As we discuss below, these two levels are related: If teachers see more in students' thinking, they may be more inclined to see student thinking as the focus of classroom activity, explaining in part their progress in responsive teaching. Many teachers commented on how having first-hand experience with the disciplinary practices of science and the feelings that arise within inquiry (such as of excitement, frustration, and vulnerability) helped them better understand and appreciate their students' experiences in the classroom.

Dione, for instance, openly discussed her struggle, and in particular, her feelings of insecurity and inadequacy at the beginning of the PD, and how those feelings positioned her to better understand her students. In her interview, Dione noted:

> The first class, everybody was like, "What?" You know, "What- I don't understand what we're supposed to be doing here." [...] Um, but it-it gave us an idea of how the kids- well at first we were all like, "Well I'm not writing that I feel stupid if I write that." And [the PD facilitators'] point was, "Well that's how the kids feel." So it was- it was kind of learning through empathy how to do it and then being able to transfer that to the kids and teach them that it's okay to think that way."

Dione elaborated on her experience of feeling "stupid" when asked to share her thinking regarding scientific phenomena and to comment on others' posts online:

> I felt- I-I don't know how to explain it. I kinda felt stupid. I guess that's the best word. Like you would go on and read what other people wrote and be like "Oh, well that's not what I was thinking. Maybe I'm wrong." […] and how [the PD facilitators] explained it was, "You might feel like that kid who's afraid to raise their hand because they think their answer is wrong." So the- [PD facilitators] had a way of - I don't know how they did this but it - they-they transformed our thinking into the thinking of the kids. Because

> in essence that's what we were. Like, we want kids to learn science, they wanted us to learn the thinking of science. So we became the kids in the classroom.

In her final reflection, Dione explained that "by being dropped into the middle of what our students feel when they begin classes" provided her with "a unique perspective." She reflected on how participating in extended scientific inquiry centered on hers and her peers' thinking "tuned [her] in" to her own students by allowing her to take *their* perspectives and to gain insight into what *they* may be experiencing. Reflecting on her own and her peers' progress in doing science, Dione added: "Just as I saw in each of us, I know I will see my new students opening up to this idea of thinking and doing science".

Other teachers similarly commented on how experiencing epistemic feelings in science—from trepidation to excitement, from frustration to enjoyment, from vulnerability and anxiety about not knowing to the motivation to pursue questions of interest— was important for fostering their epistemic empathy.

Jessica described her feelings in learning science in the ways afforded by the PD and her desire to design similar experiences for her students. She related her students' initial resistance to her new instructional approach to her own resistance at the start of the PD, where she and other teachers were uncertain about the purpose of lingering in science questions in open-ended ways (Dini et al., 2019):

> It took some time to get [my students] to let go of the expectation that we have to have a final answer, that I'm going to tell them what it is [...] even for us as *teachers* taking the course for the first several weeks, we struggled with that and learning how to adapt to that new way of thinking.

Connecting to her students' experiences in these ways helped Jessica empathize with them:

> As I reflect now, I think they were just going through the first phase I went through, of not really knowing "what it is that you want from me right now. I already told you what I think, why are you still pushing and asking me to explain more?"

Rachel relayed a similar sentiment reflecting back on her students' initial resistance and sense of discomfort sharing their own ideas in science, noting that the students may have had "the same kind of issues" that she and her peers experienced early on in the PD where they wanted the instructor to just "tell them things."

Relatedly, Carlos described how doing science and struggling to explain "very elementary" concepts helped him experience what it feels like to be a student grappling with scientific ideas, feelings that allowed him to better connect with and understand his own students' experiences:

> We were basically presented with a question that uhm- that as science educators, we- we sort of shrugged off as being very elementary, you know? I believe the question was "what makes a balloon float?" and we were like "oh." We started saying all of our answers - piece of cake - and um- and we found out very quickly that we were gonna have to delve much deeper into our understanding or-or I should probably say our lack of understanding [...] And I think I even wrote in my reflection, um after those first two days, like "wow, like that's completely different than anything I've ever participated in."
>
> [...] Thinking about those types of questions that seem, you know, again very elementary to us, but- but we found out very quickly that we- we were only scratching the surface of.

This realization, Carlos noted, "was very very eye opening" and "very humbling." He described how his own and his peers' "ego" got challenged and the feeling of worry about coming across as not "know[ing] that much." Like Dione and others, those first-hand feelings of vulnerability fostered Carlos' connections to and empathy for his students. More generally, Carlos commented on the value of doing science for teaching, noting in his interview that "we can't do this complete paradigm shift with the way that we teach science if we don't participate in it first." He explained that "really what made a difference is the tiered approach that was taken, with us trying to do the science before we tried to implement the change in our classrooms."

Gabriel wrote more specifically about how doing science in the PD, and in particular working with others to figure out phenomena and the emotions and feelings that arise in such work, influenced his goals for his students:

> I greatly enjoyed the learning community I experienced while trying to figure out different phenomena in nature with my classmates [...] I need to help [my students] see what each other is thinking just as I experienced with the balloon, the siphon, and the melting ice. [...]
>
> The excitement I felt when I was close to figuring out why helium balloons go backwards in a braking car, the feeling of predicting the rainbow experiment's results, and the lesson I learned when I realized I had "driven right past" a fundamental idea with the denser salt water being a heat transfer inhibitor are all moments I recall vividly." [...]
>
> If I can get my students to have experiences similar to these that stick with them, then they will have had a very worthwhile 7th grade science year.

Gabriel recalled both affective and intellectual aspects of his experiences, including the excitement within science explorations when he was at the edge of "figuring out" an explanation or successful in "predicting" experimental results, and the bit of pain realizing he had "driven right past a fundamental idea." Having experienced such feelings, Gabriel became driven to create similar opportunities for his own students.

In all of these excerpts, there is evidence of the role of epistemic empathy in teacher learning, and in particular of how epistemic empathy served to help stabilize their framing of class as focused on students' doing science. Teachers' experiences as science learners in the PD and the various feelings that arose as they engaged in doing science helped them relate to and appreciate their own students' experiences in the classroom, and in turn to reframe their goals for student learning. Teachers' reflections at the end of the PD provide clear evidence of these dynamics, such as in Dione's sense of responsibility that her students become better able to "take life by the horns and think"; Kayla's appreciating that her "students are eager to engage in deep thoughtful conversations and genuinely interested in what their peers are saying"; and Gabriel's saying, "If I can get my students to have experiences similar to" his, of the excitement he felt when he was "close to figuring out" an explanation or the vexation of having "driven right past" an idea, "they will have had a very worthwhile 7th grade science year."

7. Discussion and Implications

The primary goal for engaging teachers in doing science in professional learning settings has been to promote their content learning and canonical understanding of scientific ideas and concepts. More recently, the focus has shifted toward providing teachers opportunities to experience and develop facility with scientific practices so that they are better positioned to provide similar experiences for their students as called for in recent reforms (NRC, 2012).

Building on this line of work, our study contributes an empirical account of shifts in teachers' instructional practices as a result of their engagement in scientific inquiry. More specifically, our findings provide evidence that doing science for an extended period of time in a PD context that centers teachers' own explorations, ideas, questions, and feelings can support teachers to become more attentive and responsive to their own students' epistemic experiences and feelings in the classroom. Such an account is particularly useful given the scarcity of research that examines whether doing science within a PD setting may shift teachers' instructional practices.

Our work also contributes by identifying a part of *how* that happens. Our analysis showed that the PD served as a context to cultivate teachers' *epistemic empathy*— their tuning into and valuing students' intellectual and emotional experiences in science—which in turn, helped teachers reframe how they think about and approach science instruction, from centrally focusing on the canon to attending and responding to students' experiences. Ever-present concerns about progress toward the canon, that students arrive at correct answers and understanding, can tug at teachers' attention, to shift it toward the knowledge that will be on the standardized tests. Teachers' epistemic empathy can help keep their attention focused on the students' thinking and experiences, recognizing students' engagement in disciplinary practices as a priority. Such recognition may support teachers to navigate and potentially overcome larger institutional and societal framing of science teaching as about imparting a correct body of knowledge.

To be clear, we do not mean to suggest that epistemic empathy as it relates to the doing of science was the only factor that supported teachers' progress in responsive teaching. In fact, we suspect and have evidence both within this PD and from the literature to argue that other aspects of the PD experiences, including the practice of listening to student thinking in video records of classroom interactions, were also consequential for teachers' instruction. Here, we focus on epistemic empathy and its connection to teachers' extended science inquiry because of its salience in teachers' reflections on their experiences in the program, and because, to our knowledge, this aspect of teacher learning has not been discussed in research on responsive teaching.

We have discussed teachers' empathy as *epistemic,* that is, in relation to students' experiences of constructing, communicating, and critiquing knowledge (Barzilai & Chinn, 2017; Chinn, Rinehart, & Buckland, 2014; Ford, 2008), to distinguish it from other accounts of empathy in the teacher education literature—what some scholars have referred to as *cultural* empathy (Dunn & Wallace, 2004; Pedersen, Crethar, & Carlson, 2008). Those accounts discuss teachers' empathy with respect to students' families and cultural backgrounds, social and interpersonal relationships, and other life circumstances that may affect students (e.g., Aspy, 1972; Chang, Berger, & Chang, 1981; Dolby, 2012; Feshbach & Feshbach, 2009; Tettegah & Anderson, 2007; Warren, 2018). For example, researchers discuss how teachers' empathy is important for socio-emotional learning, for reducing aggression, and for fostering a sense of belonging to the classroom community (e.g., Arghode, Yalvac, & Liew, 2013; Cassidy & Bates, 2005). Researchers also argue that empathy is key for culturally responsive pedagogy and specifically for teaching racially, linguistically, and ethnically diverse students (e.g., Dolby, 2012; Howard & Milner, 2014; McAllister & Irvine, 2002; Rychly & Graves, 2012; Warren, 2013, 2014, 2017). This is especially the case for white teachers, Warren (2017) argues, as such empathy can allow them to adopt "the social perspectives of others" (p. 169) which would position them to better understand diverse students' communities, social lives, and ways of being that may be very different from those of the teachers.

While those considerations are essential for teaching, such accounts conceptualize empathy as occurring outside of, and at times separate from, students' *epistemic* experiences (Jaber, Southerland, & Dake, 2018). In other words, the aforementioned portrayals of empathy do not encompass aspects of teachers' empathy that are specifically directed at and in support of learners' epistemic pursuits. With its emphasis on epistemic dimensions, epistemic empathy, we have argued, is particularly important for understanding teacher learning and responsive teaching as it provides teachers a window into students' sensemaking experiences and their ways of reasoning and feeling within epistemic activities. Such a window is essential for recognizing, interpreting, and building on the productive beginnings in student thinking in ways that honor and support students' disciplinary work and progress.

Our perspective on epistemic empathy intersects with theoretical accounts and frameworks from psychology and cognitive science, including the central tenet of Theory of Mind (ToM) which posits that people have a capacity to infer others' mental states, such as their beliefs, desires, and intentions. This capacity helps one understand and anticipate how another person might act or reason in certain situations (Kloo, Perner, & Giritzer, 2010; Meltzoff, 1999). Epistemic empathy also connects with recent accounts in philosophy where scholars are considering the role of empathy in knowledge development, such as in understanding the construction of arguments and judgments (Oxley, 2011; Steinberg, 2014) and in analyzing and interpreting historical events (Stuber, 2008). Building on these points, we suspect that epistemic empathy may inform and enhance other types of teacher empathy, including cultural empathy. By providing access to and appreciation of the varied experiential, emotional, and linguistic resources that students recruit to make sense of phenomena, epistemic empathy may allow teachers to know students not only as scientific thinkers but also more holistically as people.

In foregrounding epistemic empathy, our work provides new insight into how the doing of science can support teachers to become more responsive in the classroom. By being positioned as learners in the PD, experiencing the feelings of excitement, frustration, and vulnerability in doing science, teachers gained perspective into how their students may act, think, and feel. Experiencing the drives and practices of the discipline allowed teachers to see value in providing similar experiences for their students. As Duckworth (2006) argues: "It is just as necessary for teachers as for children to feel confidence in their own ideas. It is important for them as people and it is important in order for them to feel free to acknowledge the children's ideas" (p.8). When teachers acknowledge students' intellectual and emotional work in science, they can teach in ways that honor students' experiences and cultivate productive disciplinary dispositions for learning (Jaber, 2016; Jaber & Hammer, 2016; Lehrer, 2009; Miller et al, 2018; Scardamalia & Bereiter, 2014; Stroupe, 2014).

Considering the value of epistemic empathy in instruction has several implications for the design of teacher education and PD programs. For one, it supports responsive practices of engaging teachers in doing science for themselves, in particular for their having rich experiences of what it *feels* like to do science. In this it suggests designing PD with the explicit goal of teachers' having these feelings entangled with the epistemic features of scientific practices, as discussed in standards and research (Ford, 2008; NGSS, 2013). Further, it suggests the value of explicit discussion of these feelings and how they inhere in doing science, including the "negative" feelings of uncertainty and vexation, which teachers and students may, like scientists, come to enjoy (Radoff, Jaber, & Hammer, 2019).

We have proposed the notion of epistemic empathy as a particular value of teachers' experiences of science in their PD. Going forward, we suggest it as a focus of further research, including as it may concern equity. We worry, for example, that people are more likely to empathize with those who look and sound like them, for example people of the same cultural, racial, or linguistic background. For this reason, teachers' epistemic empathy might be a mechanism of advantage for some students at the expense of others, and therefore unintendedly reinforce existing inequities in the science fields. If so, how can we work to prevent such perils?

Can cultural empathy serve as a tool in tandem with epistemic empathy to foster unbiased and socially just responsive teaching? These questions motivate further research on both epistemic and cultural empathy, research that may be critical to move the field forward toward equitable responsive instruction for all students.

References

Arghode, V., Yalvac, B., & Liew, J. (2013). Teacher empathy and science education: A collective case study. Eurasia Journal of Mathematics, Science & Technology Education, 9(2), 89-99.

Aspy, D. N. (1972). Toward a technology for humanizing education. Champaign, IL: Research Press.

Atkins, L., & Frank, B. (2016). Examining the products of responsive inquiry. In A.D. Robertson, R.E. Scherr, & D. Hammer (Eds.), Responsive teaching in science and mathematics (pp. 56-84). New York, NY: Routledge.

Ball, D. L. (1993). With an eye on the mathematical horizon: Dilemmas of teaching elementary school mathematics. The Elementary School Journal, 93(4), 373-397.

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). Report of the 2018 NSSME+. Chapel Hill, NC: Horizon Research, Inc.

Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). Report of the 2012 National Survey of Science and Mathematics Education. Chapel Hill, NC: Horizon Research, Inc.

Barzilai, S., & Chinn, C. A. (2018). On the goals of epistemic education: promoting apt epistemic performance. Journal of the Learning Sciences, 27(3), 353-389.

Berland, L. K., & Hammer, D. (2012). Framing for scientific argumentation. Journal of Research in Science Teaching, 48 (1), 68-94.

Bing, T. J., & Redish, E. F. (2009). Analyzing problem solving using math in physics: Epistemological framing via warrants. Physical Review Special Topics-Physics Education Research, 5(2), 020108.

Capps, D. K., Crawford, B. A., & Constas, M. A. (2012). A review of empirical literature on inquiry professional development: Alignment with best practices and a critique of the findings. Journal of science teacher education, 23(3), 291-318.

Cassidy, W., & Bates, A. (2005). "Drop-outs" and "push-outs": Finding hope at a school that actualizes the ethic of care. American Journal of Education, 112(1), 66-102.

Chang, A. F., Berger, S. E., Chang, B. (1981). The relationship of student self-esteem and teacher empathy to classroom learning. Psychology: A Journal of Human Behavior, 18(4), 21-25.

Chinn, C. A., Rinehart, R. W., & Buckland, L. A. (2014). Epistemic cognition and evaluating information: Applying the AIR model of epistemic cognition. In D.N. Rapp & J.L.G. Braasch (Eds.), Processing inaccurate information: Theoretical and applied perspectives from cognitive science and the educational sciences (pp. 425-453). Cambridge, MA: MIT Press.

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. Journal of Research in Science Teaching, 48 (10), 1109-1136.

Colley, C., & Windschitl, M. (2016). Rigor in elementary science students' discourse: The role of responsiveness and supportive conditions for talk. Science Education, 100(6), 1009-1038.

Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., Hall, R., Koschmann, T., Lemke, J., Sherin, M. G., & Sherin, B. L. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. The Journal of the Learning Sciences, 19(1), 3-53.

Dini, V., Jaber, L., & Danahy, E. (2019). Dynamics of scientific engagement in a blended online learning environment. Research in Science Education, 1-29.

Dolby, N. (2012). Rethinking multicultural education for the next generation: The new empathy and social justice. New York, NY: Routledge.

Dorph, R., & Chi, B. (2013). Productive Beginnings: The Final Evaluation Report for the Learning Progressions in Scientific Inquiry and Energy Project (NSF# 0732233). University of California, Berkeley, CA, 37.

Duckworth, E. (1986/2001). Inventing Density. In: Eleanor Duckworth (ed.). "Tell me more": Listening to learners explain, New York: Teacher's College Press, 1-41.

Duckworth, E. (2006). The having of wonderful ideas and other essays on teaching and learning (3rd Edition). New York, NY: Teachers College Press.

Dunn, L., & Wallace, M. (2004). Australian academics teaching in Singapore: Striving for cultural empathy. Innovations in education and teaching international, 41(3), 291-304.

Einstein, A. (1936). Physics and reality. Journal of the Franklin Institute, 221.

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). New York, NY: Cambridge University Press.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. Cognition and Instruction, 20(4), 399-483.

Feshbach, N. D., & Feshbach, S. (2009). Empathy and education. In J. Decety & W. Ickes (Eds.), The social neuroscience of empathy (pp. 85-98). Cambridge, MA: The Massachusetts Institute of Technology Press.

Ford, M. J. (2008). "Grasp of practice" as a reasoning resource for inquiry and nature of science understanding. Science & Education, 17(2&3), 147-177.

Ford, M. J. (2015). Educational implications of choosing "practice" to describe science in the next generation science standards. Science Education, 99, 1041-1048.

Ford, M. J., & Forman, E. A. (2006). Redefining disciplinary learning in classroom contexts. Review of research in education, 30(1), 1-32.

Forman, E. A., & Ford, M. J. (2014). Authority and accountability in light of disciplinary practices in science. International Journal of Educational Research, 64, 199-210.

Geiger, V., Muir, T., & Lamb, J. (2016). Video-stimulated recall as a catalyst for teacher professional learning. Journal of Mathematics Teacher Education, 19(5), 457-475.

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

González-Howard, M., & McNeill, K. L. (2019). Teachers' framing of argumentation goals: Working together to develop individual versus communal understanding. Journal of Research in Science Teaching, 56(6), 821-844.

Ha, H., & Kim, H. B. (2017). Exploring responsive teaching's effect on students' epistemological framing in small group argumentation. Journal of the Korean Association for Science Education, 37(1), 63-75.

Hammer, D. (1997). Discovery learning and discovery teaching. Cognition and Instruction, 15(4), 485-529.

Hammer, D., & van Zee, E. H. (2006). Seeing the science in children's thinking: Case studies of student inquiry in physical science. (Book and DVD) Portsmouth, NH: Heinemann.

Hammer, D., Elby, A., Scherr, R. E., & Redish, E. F. (2005). Resources, framing, and transfer. In J. Mestre (Ed.), Transfer of Learning from a Modern Multidisciplinary Perspective (pp. 89-120). 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.

Hammer, D., Russ, R., Mikeska, J., & Scherr, R. (2008). Identifying inquiry and conceptualizing students' abilities. In R. Duschl & R. Grandy (Eds). Establishing a Consensus Agenda for K-12 Science Inquiry (pp. 138-156). Rotterdam, NL: Sense Publishers.

Hawkins, D. (1965). Messing about in science. Science and children, 5-9.

Howard, T. C., & Milner, H. R. (2014). Teacher preparation for urban schools. Handbook of urban education, 11(3), 199-216.

Hutchison, P., & Hammer, D. (2010). Attending to student epistemological framing in a science classroom. Science Education, 94(3), 506-524.

Jaber, L. Z. (2016). Attending to students' epistemic affect. In A. D. Robertson, R. E. Scherr & D. Hammer (Ed.), Responsive teaching in science and mathematics (pp. 162-188). New York, NY: Routledge.

Jaber, L. Z., Dini, V., Hammer, D., & Danahy, E. (2018). Targeting disciplinary practices online with a responsive teaching approach. Science Education, 102(4), 668-692.

Jaber, L. Z., & Hammer, D. (2016). Learning to feel like a scientist. Science Education, 100(2), 189-220.

Jaber, L. Z., Hufnagel, E., & Radoff, J. (2019). "This is Really Frying My Brain!": How Affect Supports Inquiry in an Online Learning Environment. Research in Science Education, 1-24.

Jaber, L. Z., Southerland, S., & Dake, F. (2018). Cultivating epistemic empathy in preservice teacher education. Teaching and Teacher Education, 72, 13-23.

Jimenez-Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. Science Education, 84(6), 757-792.

Kloo, D., Perner, J., & Giritzer, T. (2010). Object-based set-shifting in preschoolers: Relations to theory of mind. In B. W. Sokol, U. Muller, J. I. M. Carpendale, A. R. Young, & G. Iarocci (Eds.), Self-and social-regulation: Exploring the relations between social interaction, social cognition, and the development of executive functions, 193-218. (pp. 193–217). Oxford, UK: Oxford University Press.

Ko, M. L. M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. Science Education, 103(4), 979-1010.

Lehrer, R. (2009). Designing to develop disciplinary dispositions: Modeling natural systems. American Psychologist, 64(8), 759.
Levin & Richards, 2011Levin, D. M., Hammer, D., & Coffey, J. E. (2009). Novice teachers' attention to student thinking. Journal of Teacher Education, 60(2), 142-154.
Levin, D. M., Hammer, D., Elby, A., & Coffey, J. (2012). Becoming a responsive science teacher: Focusing on student thinking in secondary science. Arlington VA: NSTA Press.
Levin, D. M., & Richards, J. (2011). Learning to Attend to the Substance of Students' Thinking in Science. Science Educator, 20(2), 1-11.
MacLachlan, G. L., & Reid, I. (1994). Framing and interpretation. Melbourne University Press.
Manz, E. (2015). Resistance and the development of scientific practice: Designing the mangle into science instruction. Cognition and Instruction, 33(2), 89-124.
Maskiewicz, A. C. (2016). Navigating the challenges of teaching responsively: An insider's perspective. In A.D. Robertson, R.E. Scherr, & D. Hammer (Eds.), Responsive teaching in science and mathematics (pp. 123-143). New York, NY: Routledge.
Maskiewicz, A., & Winters, V. (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.
McAllister, G., & Irvine, J. J. (2002). The role of empathy in teaching culturally diverse students a qualitative study of teachers' beliefs. Journal of Teacher Education, 53(5), 433-443.
Mehan, H. (1979). Learning lessons. Cambridge, MA: Harvard University Press.
Meltzoff, A. N. (1999). Origins of theory of mind, cognition and communication. Journal of Communication Disorders, 32(4), 251-269.
Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. Journal of Research in Science Teaching, 55(7), 1053-1075.
Moon, J., Michaels, S., & Reiser, B. J. (November 2012). Science standards require a teacher-learning rethink. Education Week. Retrieved from http://www.edweek.org/ew/articles/2012/11/30/13moon.h32.html
National Research Council (NRC). (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core Ideas. Washington, DC: National Academies Press.
Next Generation Science Standards (NGSS) Lead States. (2013). Next Generation Science standards: For states, by states. Washington, DC: The National Academies Press.
Oxley, J. (2011). The moral dimensions of empathy. Limits and applications in ethical theory and practice. London, UK: Palgrave Macmillan.
Passmore, C. (2014). Implementing the Next Generation Science Standards: How your classroom is framed is as important as what you do in it. National Science Teaching Association Blog, 11, 10-14.
Pedersen, P. B., Crethar, H. C., & Carlson, J. (2008). Inclusive cultural empathy: Making relationships central in counseling and psychotherapy. American Psychological Association.
Pierson, J. L. (2008). The Relationship Between Patterns of Classroom Discourse and Mathematics Learning Unpublished doctoral dissertation. Mathematics Education. University of Texas at Austin. Austin, TX.
Radoff, J., Jaber, L.Z, & Hammer, D. (2019). "It's Scary but It's Also Exciting": Evidence of Meta-Affective Learning in Science. Cognition and Instruction 37(1), 73-92.

Radoff, J., Robertson, A. D., Fargason, S., & Goldberg, F. (2018). Responsive teaching and high-stakes testing: Does deviating from the curriculum to pursue students' ideas mean they will perform poorly? Science and Children, 55(9), 88-91.

Redish, E. F. (2004). A theoretical framework for physics education research: Modeling student thinking. arXiv preprint physics/0411149.

Reiser, B. J., Michaels, S., Moon, J., Bell, T., Dyer, E., Edwards, K. D, McGill, T. A. W., Novak, M., & Park, A. (2017). Scaling up three-dimensional science learning through teacher-led study groups across a state. Journal of Teacher Education, 68(3), 280-298.

Richards, J., & Robertson, A. D. (2016). A review of the research on responsive teaching in science and mathematics. In A.D. Robertson, R.E. Scherr, & D. Hammer (Eds.), Responsive teaching in science and mathematics (pp. 36-55). New York, NY: Routledge.

Richards, J., Elby, A., Luna, M. J., Robertson, A. D., Levin, D. M., & Nyeggen, C. G. (2020). Reframing the Responsiveness Challenge: A Framing-Anchored Explanatory Framework to Account for Irregularity in Novice Teachers' Attention and Responsiveness to Student Thinking. Cognition and Instruction, 38(2), 116-152.

Robertson, A. D., Atkins, L. J., Levin, D. M., & Richards, J. (2015). What is responsive teaching?. In A.D. Robertson, R.E. Scherr, & D. Hammer (Eds.), Responsive teaching in science and mathematics (pp. 19-53). New York, NY: Routledge.

Robertson, A. D., & Richards, J. (2017). Teacher sense-making about being responsive to students' science ideas: A case study. European Journal of Science and Mathematics Education, 5(4), 314-342.

Robertson, A. D., Scherr, R. E., & Hammer, D. (2016). Responsive teaching in science and mathematics. New York, NY: Routledge.

Rosebery, A. S., Warren, B., & Tucker-Raymond, E. (2016). Developing interpretive power in science teaching. Journal of Research in Science Teaching, 53(10), 1571-1600.

Rosenberg, S.A., Hammer, D., & Phelan (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., Coffey, J. E., Hammer, D., & Hutchison, P. (2009). Making Classroom Assessment More Accountable to Scientific Reasoning: A Case for Attending to Mechanistic Thinking. Science Education, 93(5), 875-891. Rosebery, A. S., Warren, B., & Tucker-Raymond, E. (2016). Developing interpretive power in science teaching. Journal of Research in Science Teaching, 53(10), 1571-1600.

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.

Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. Journal of Research in Science Teaching, 50(3), 284-314.

Rychly, L., & Graves, E. (2012). Teacher characteristics for culturally responsive pedagogy. Multicultural Perspectives, 14(1), 44-49.

Saldaña, J. (2015). The Coding Manual for Qualitative Researchers. London, UK: Sage Publications.

Salter, I., & Atkins, L. (2013). Student-generated scientific inquiry for elementary education undergraduates: course development, outcomes and implications. Journal of Science Teacher Education, 24(1), 157-177.

Santagata, R., & Taylor, K. (2018). Novice Teachers' Use of Student Thinking and Learning as Evidence of Teaching Effectiveness: A Longitudinal Study of Video-Enhanced Teacher Preparation. Contemporary Issues in Technology and Teacher Education, 18(1), 11-28.

Scardamalia, M. (2000). Can schools enter a Knowledge Society? In M. Selinger and J. Wynn (Eds.), Educational technology and the impact on teaching and learning (pp. 6-10). Abingdon, Eng.: Research Machines.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. Liberal Education in a Knowledge Society, 97, 67-98.

Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: Theory, pedagogy, and technology. In K. Sawyer (Ed.), Cambridge handbook of the learning sciences (2nd edition., pp. 397-417). New York: Cambridge University Press.

Scherr, R. E., & Hammer, D. (2009). Student Behavior and Epistemological Framing: Examples from Collaborative Active-Learning Activities in Physics. Cognition and Instruction, 27(2), 147-174.

Schwarz, C. V., Passmore, C., & Reiser, B. J. (2017). Helping students make sense of the world using next generation science and engineering practices. NSTA Press.

Shaban, Y., & Wilkerson, M. H. (2019). The co-construction of epistemological framing in clinical interviews and implications for research in science education. International Journal of Science Education, 41(12), 1579-1599.

Shim, S. Y., & Kim, H. B. (2018). Framing negotiation: Dynamics of epistemological and positional framing in small groups during scientific modeling. Science Education, 102(1), 128-152.

Sikorski, T.-R. (2016). Understanding responsive teaching and curriculum from the students' perspective. In A. D. Robertson, R. E. Scherr & D. Hammer (Eds.), Responsive teaching in science (pp. 85–104). New York, NY: Routledge.

Sinclair, J. M., & Coulthard, M. (1975). Toward an analysis of discourse: The English used by teachers and pupils. Oxford University Press.

Steinberg, J. (2014). An epistemic case for empathy. Pacific Philosophical Quarterly, 95(1), 47-71.

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. Science Education, 98(3), 487-516.

Stroupe, D. (2016). Beginning teachers' use of resources to enact and learn from ambitious instruction. Cognition and Instruction, 34(1), 51-77.

Stueber, K. R. (2008). Reasons, generalizations, empathy, and narratives: The epistemic structure of action explanation. History and Theory, 47(1), 31-43.

Tannen, D. (1993). What's in a frame? Surface evidence for underlying expectations. Framing in discourse, 14, 56.

Tekkumru-Kisa, M., & Stein, M. K. (2015). Learning to see teaching in new ways: A foundation for maintaining cognitive demand. American Educational Research Journal, 52(1), 105-136.

Tekkumru-Kisa, M., Stein, M. K., & Coker, R. (2018). Teachers' learning to facilitate high-level student thinking: Impact of a video-based professional development. Journal of Research in Science Teaching, 55(4), 479-502.

Tettegah, S., & Anderson, C. J. (2007). Pre-service teachers' empathy and cognitions: Statistical analysis of text data by graphical models. Contemporary Educational Psychology, 32(1), 48-82.

Thompson, J., Hagenah, S., Kang, H., Stroupe, D., Braaten, M., Colley, C., & Windschitl, M. (2016). Rigor and responsiveness in classroom activity. Teachers College Record.

van de Sande, C. C., & Greeno, J. G. (2012). Achieving alignment of perspectival framings in problem-solving discourse. Journal of the Learning Sciences, 21(1), 1-44.

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A. S., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday sense-making. Journal of Research in Science Teaching, 38(5), 529-552.

Warren, C. A. (2013). The Utility of Empathy for White Female Teachers' Culturally Responsive Interactions with Black Male Students. Interdisciplinary Journal of Teaching and Learning, 3(3), 175-200.

Warren, C. A. (2014). Toward a pedagogy for the application of empathy in culturally diverse classrooms. The Urban Review, 46(3), 395-419.

Warren, C. A. (2017). Urban Preparation: Young Black Men Moving from Chicago's South Side to Success in Higher Education. Harvard Education Press.

Warren, C. A. (2018). Empathy, teacher dispositions, and preparation for culturally responsive pedagogy. Journal of Teacher Education, 69(2), 169-183.

Watkins, J., Coffey, J. E., Maskiewicz, A. C., & Hammer, D. (2017). An account of teachers' epistemological progress in science. In G. Schraw, J. Lunn Brownlee, L. Olafson & M. VanderVeldt Brye (Eds.), Teachers' Personal Epistemologies: Evolving Models for Informing Practice. (pp. 89-113). Charlotte, NC: Information Age Press.

Watkins, J., Jaber, L. Z., & Dini, V. (2020). Facilitating scientific engagement online: Responsive teaching in a science professional development program. Journal of Science Teacher Education, 31(5), 515-536.

Watkins, J., Phillips, A. M., Radoff, J., Jaber, L. & Hammer, D. (2018). Positioning as not-understanding: The value of showing uncertainty for engaging in science. Journal of Research in Science Teaching, 55(4), 573-599.

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. Science Education, 96(5), 878-903.