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ARTICLE

Cultivating Science Teachers' Understandings of Science as a Discipline

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Abstract
Current visions of science education advocate that students should engage with science in the classroom in ways that mirror the work of scientists in order to develop science proficiency. For this goal, teachers are tasked with the complex responsibility of supporting students in understanding not only the conceptual knowledge of science, but also its disciplinary practices, norms, and epistemologies. In order for teachers to teach in such ways, they must be afforded opportunities to develop and reflect on their own disciplinary understandings about science. Research Experiences for Teachers' (RETs) programs, in which teachers engage in research with scientists, may be fertile contexts for the development of teachers' robust understandings about science. As such, the purpose of this naturalistic single-case study is to explore the ways in which one elementary teacher (Ava) describes shifts in her disciplinary understandings about science after participating in a 6-week summer Research Experience for Teachers' program. Through examination of interviews and observations, this study takes a critical event narrative analysis approach to unpack the ways in which Ava interprets certain disciplinary understandings about science in light of events during her research experience that *to her* had lasting and important impact on her understandings of science. We conclude by discussing the implications of this work for research and professional development design.

1 Introduction

Current visions for science learning in K-12 classrooms advocate that students should engage with science in ways that mirror the work of scientists in order to develop proficiency in the discipline (National Research Council [NRC], 2012). From this lens, the goal of science education is not only to provide students with the conceptual knowledge of science, but also to give them opportunities to practice the doing of science and to gain epistemological insights about the discipline (Duschl, 2008; Engle & Conant, 2002; Ford, 2008; Hodson, 2014; Kelly, 2018).

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Ideally, such learning will also move beyond simply learning content knowledge to include overturning assumptions about who is allowed access to the scientific community or viewed as capable in science (Chambers, 1983; Sharkawy, 2009) and complexifying the notion that science is straightforward and procedural in nature (Harwood et al., 2005; Stroupe, 2014). It should also include supporting students in coming to know and use the discursive practices of constructing explanations from evidence and evaluating claims through argumentation (Ford, 2008; Ryu & Sandoval, 2012; Zembal-Saul et al., 2013). Further, the development of science proficiency would help students in navigating the emotions and feelings they encounter as they participate in science work in the classroom (Jaber & Hammer, 2016a, b; Davidson et al., 2020).

To be effective in supporting students in learning the conceptual knowledge of science *and* its disciplinary practices and epistemological underpinnings, teachers themselves must have opportunities to develop and reflect on their own understandings about science (Passmore, 2014; Reiser, 2013). Yet, few teachers have such opportunities, such as being involved in scientific research, to refine their disciplinary understandings. This unfamiliarity with *doing science* makes it difficult for teachers to translate the practices and epistemologies of the discipline into their classroom (Banilower et al., 2013; Capps et al., 2012; Hodson, 2014).

One context that holds great potential for engaging teachers in scientific work lies in Research Experience for Teachers' (RETs) programs. Such programs have been instituted at national laboratories and universities as professional development venues wherein K-12 teachers participate in extensive research through collaborative work with scientists (Enderle et al., 2014; Dixon & Wilke, 2007; SRI International, 2007). Because of their immersive nature, RET programs can be fruitful access points for teachers to develop refined understandings about science.

Much of the prior research around RET programs has attended to the ways in which such immersive experiences can promote change in teachers' views about science inquiry and the nature of science. For example, some studies have noted that some teachers' understandings have shifted from naïve to more sophisticated conceptions of science after participating in RET programs (Anderson & Moeed, 2017; Blanchard et al., 2009; Buxner, 2014; Grove et al., 2009; Varelas et al., 2005). However, these studies also note that, while measurable through surveys and pre-post interviews, changes in teachers' understandings were often small in nature or were mostly seen in those who entered the program with more nuanced understandings to begin with (Blanchard et al., 2009; Buxner, 2014). Moreover, studies have suggested that if substantial changes in teachers' understanding about science are sought, the research experience needs to have specific characteristics to engender such change. Possible characteristics include the degree of agency and choice teachers have over their research experience and its relation to their own interests (Southerland et al., 2016) and the nature of the social interactions that the teachers have with scientists and others in their lab (Southerland et al., 2016; Davidson & Hughes, 2018).

In sum, as "intuitively pleasing" (Blanchard et al., 2009, p. 322) as RET programs can seem, participation in such a program does not guarantee that teachers will come away with more sophisticated understandings about disciplinary content, practices, or epistemologies in science. When teachers do experience and articulate lasting shifts or new realizations in their disciplinary understandings as a result of RET participation, we argue that it is important to understand *how* these changes have come about in order to create future research experiences that are more supportive of teacher learning and change.

Within the context of RET programs, teachers experience many moments, events, and interactions in the field or laboratory that are designed to deepen their understandings of science. Conversely, teachers may also experience events and interactions that are unplanned but nonetheless become critical in shaping their disciplinary understandings. By attending to and taking seriously those events which teachers themselves report as important for their disciplinary understandings, an approach known as critical event narrative analysis (Avraamidou, 2016; Webster & Mertova, 2007), researchers can gain insight into teachers' emergent understandings of science that may otherwise remain unnoticed.

To our knowledge, no studies have explicitly examined what teachers themselves identify as particularly productive components in their research experiences and how certain events within their RET participation might shape their understandings about the discipline of science. This study begins to address this gap by exploring how one elementary teacher describes shifts in her understandings about science in light of personally relevant and meaningful events that occurred during her participation in scientific research.

In the remainder of this work, we draw on philosophical arguments in science education to discuss the ways in which our field has framed epistemic understandings about the discipline of science that inform current views of science education. We then examine how RET programs may serve as fertile contexts for teachers to develop disciplinary understandings through encounters with "critical events" during their RET participation. Building on this, we present our study of one elementary teacher's emergent and shifting understandings about science in a 6-week RET program and discuss the ways in which particular events were consequential for her understandings. We conclude by discussing the implications of this work for research and professional development design.

2 Theoretical Perspectives and Related Literature

2.1 Views of Disciplinary Understandings About Science

The epistemological underpinnings and assumptions of what science is, how it is done, and who practices science have long been a matter of debate for philosophers, historians, and sociologists of science and even scientists themselves—not to mention researchers in science education concerned with those aspects of science that form an important part of students' wider scientific proficiency (Duschl, 2008; Ford, 2008; Hodson, 2014; Schweingruber et al., 2007). Because this study is largely focused on how teachers come to understand aspects of the discipline of science, we draw from examples within science education to discuss various views on "disciplinary understandings about science." Before moving on, however, it is important to describe what we mean by disciplinary understandings about science in the context of this study.

Research in the fields of philosophy of science and sociology of science has typically explored the discipline of science through two distinct lenses. Philosophy of science is generally concerned with that which is unique about the discipline (Curd et al., 2013) in terms of how it differs from other human endeavors and activities and the epistemological tenets which separate science from non-scientific pursuits. The sociology of science, on the other hand, has traditionally focused on the work of scientists as socially and culturally situated and asks questions about scientists' practices, dispositions, and qualities they bring to their scientific work as they interact within a community of science practice (Grinnell, 2009; Zuckerman, 1988). Taken together, research from these fields has served to further the understanding that science as a discipline is a complex human endeavor wherein culture, practice, epistemic orientations, and knowledge constructed about the natural world intersect in ways that push beyond essentialist or siloed views of what science is and how it is done.

For this work, we refer to disciplinary understandings about science from a holistic view to mean those constructs that include considerations for not only the epistemic dimensions of science but also for the social, conceptual, material, and affective dimensions of science as it is practiced in laboratory and field settings. In this way, "disciplinary understandings about science" is meant to encompass the characteristics and features of scientific work; the norms, practices, and tools of the community in which that work occurs; the sociopolitical and cultural contexts that influence science, the humanity, individuality, and identities of scientists; and the conceptual knowledge and epistemological reasoning scientists use to develop new understandings about the natural world. As such, we view disciplinary understandings as interwoven constructs that, while possible to parse, are still connected. However, this view has not always been the view of the field.

From a historical view of science education in the USA, disciplinary understandings about science were seen as more positivistic in nature (Burbules & Linn, 1991; Rudolph, 2002) during Cold War era science education, wherein curricula implicitly asserted science as a fully objective, logic-driven, and truth-oriented endeavor for those who would eventually become scientists. With an aim toward placing students into a science career "pipeline" (Duschl, 2008; Rudolph, 2002), science content was largely presented as factual information to be memorized through textbooks and lectures, and doing science was presented as procedural laboratory experiences with predetermined outcomes (Rudolph, 2002).

Subsequent science education reform efforts in the late twentieth century began to consider more broadly the import of "science for all," wherein the goal of science education was to create a more scientifically literate population (Rutherford & Ahlgren, 1991) for the purposes of developing a citizenry that would be more able to engage with "the economic and democratic agendas of our increasingly global market-focused science, technology, engineering, and mathematics (STEM) societies" (Duschl, 2008, p. 268). This more recent orientation toward science education included discussion of disciplinary understandings about science that move beyond the largely positivistic views previously emphasized (Rutherford & Ahlgren, 1991); some of these included the nature of scientific inquiry, the notion that science is a social endeavor, the importance of evidence and explanation, and the tentative nature of scientific knowledge.

While there was a newfound consideration for such aspects of science in science education, consensus as to what aspects should be included and how these should be taught were not originally addressed. Over time, some scholars suggested that disciplinary understandings about science should include specific tenets of the nature of science or of scientific inquiry as described by some philosophers of science (Lederman et al., 2002; Schwartz et al., 2008). Others have critiqued this view of disciplinary understanding as essentialist and have called instead for more practice-oriented and contextually relevant views of science (Hodson & Wong, 2017). Moreover, other views may extend on these tenets of science to include considerations of culture, language, historical and political contexts, economic aspects of science, and the personal relevance of science knowledge (Dagher & Erduran, 2016; Hodson & Wong, 2017; Lave & Wenger, 1991; Longino, 2002). Such views may acknowledge how particular political, cultural, and social structures influence the types of questions scientists are able to pursue. These views also recognize that it is the people in the disciplinary community of science that mutually decide and agree upon the norms and practices of the community.

In alignment with this broad view of disciplinary understandings, current reform efforts assert that students should be afforded opportunities to think, act, behave, and feel as scientists do (NGSS Lead States, 2013; NRC, 2012). While there are limits imposed by the differences between the epistemic aims of practicing scientists and those of students in science classrooms, students are certainly capable of engaging in the disciplinary norms, practices, epistemic orientations, and knowledge-building work of science in ways that mirror the disciplinary engagement of scientists. Through learning opportunities that center scientific engagement in these ways, students can come to understand that scientists hold themselves accountable to their counterparts within a scientific community (Lave & Wenger, 1991; Traweek, 1988), they can participate in knowledge construction through argumentation (Okasha, 2002), and they can practice habitual stances of skepticism, tenacity, and curiosity toward their work (Gauld, 2005; Wenning, 2009). Additionally from this view, understanding the discipline of science also includes acknowledgement of the humanity of scientists as they manage the affective experiences—such as frustration, puzzlement, wonder, and joy—that accompany scientific endeavors (Arango-Munoz, 2014). Navigating feelings and emotions in science may be implicit, but it is important to recognize that such navigation is a necessary part of doing science (Jaber & Hammer, 2016a, b). Scientists must, for example, manage frustration in the face of a setback in order to persevere and problem-solve or temper the excitement of a potential new discovery or breakthrough with skepticism toward their findings.

Disciplinary understandings about science—as we have described them—have driven the ways in which the science education community has oriented to what matters for students' science learning, and this orientation greatly influences what and how science teachers teach. In the next section, we discuss how RET programs may be important contexts to support teachers in developing disciplinary understandings of science.

2.2 RETs as Contexts for Promoting Teachers' Disciplinary Understandings

Current visions for science learning (NRC, 2012) necessitate that teachers' instructional planning and classroom practice position students as learners, doers, and thinkers in science. In order to effectively design and support such learning opportunities for students, we argue that K-12 teachers should be afforded opportunities to become familiar with scientific work and to grasp how epistemic underpinnings and assumptions influence scientific research in communities of practice (Ford, 2008).

Yet this is a difficult expectation to place on many teachers who may have had little experience in doing science for themselves. Much of in-service teacher knowledge of science is developed in the context of undergraduate science coursework or laboratory experiences wherein scientific work is often portrayed as confirmatory labs with prescribed procedures, featuring limited opportunities for explicit reflection about the discipline of science (AAAS, 2012; Banilower et al., 2013; Fulp, 2002). In some cases, K-12 science teachers may have had some opportunities for laboratory experiences that more closely parallel the work of "real-world" scientists, but this is a fairly rare occurrence for in-service secondary teachers and even more so for elementary teachers who are particularly critical for shaping students' earliest science experiences (Banilower et al., 2013).

One potential context that could support teachers—elementary and secondary alike—in experiencing and reflecting on their disciplinary understandings about science is that of RET programs. Because RETs often require sustained participation in research over multiple weeks, such programs may serve as important contexts in which teachers not only engage in scientific work but interact with and experience a science community of practice (Davidson & Hughes, 2018). As such, RETs may allow teachers to recognize, reflect upon, and refine their understandings about science, understandings on which this present study focuses using the lens of critical event analysis. In the next section, we describe critical event analysis as a useful approach for examining the ways in which RET participants come to experience shifts in their disciplinary understandings about science.

2.3 Critical Events and Teachers' Research Experiences

Research on teacher learning around RETs suggests that teachers often benefit from their participation in terms of increased content knowledge, changes in conceptions of the nature of science, changes in beliefs about certain aspects of scientific research, and improvements in their abilities to communicate and participate in scientific discourse (Anderson & Moeed, 2017; Buck, 2003; Dixon & Wilke, 2007; Dresner & Worley, 2006; Faber et al., 2014; Hofstein & Lunetta, 2004; McLaughlin & MacFadden, 2014). However, while RETs are largely considered to be impactful experiences for teachers, there is still much to be understood about why and how RET participation is such a profound experience. RET professional development programs are often treated as a "black box" (Southerland et al., 2016, p. 3), and such "black box" investigations do little to shed light on *how* changes in disciplinary understanding occur for teachers.

At the outset of this work, we conjectured that over the course of a sustained research experience such as an RET, teachers encounter particular moments or events—critical events—that are fundamentally important to how they understand and view the discipline of science. Examining such events for teachers through the lens of critical event narrative analysis may offer key insights into how teachers come to view the discipline of science in more nuanced ways through their research participation.

Critical event narrative analysis contends that all people have lived experiences that shape the narratives they hold about their beliefs, attitudes, and understandings about the world and themselves (Webster & Mertova, 2007). Lived experiences are considered "critical" when they serve as an anchoring event by which beliefs, attitudes, and understandings of the world and oneself are upended (Webster & Mertova, 2007; Woods, 1993). Critical event analysis assumes that (a) what makes an event "critical" is the impact it has on the person to whom it has happened; (b) it is only in retrospect that the event can be seen as critical; (c) the more time that passes between the event and continued recall of the event by the experiencer, the more impactful the event has been; and (d) critical events almost always become "change events" in which some worldview or belief has been challenged and must be accommodated by the experiencer (Avraamidou, 2016; Webster & Mertova, 2007). With these assumptions in mind, drawing on such events as focal data in research can provide "valuable and insightful tools for getting at the core of what is important in that research" (Webster & Mertova, 2007, p. 71).

Critical events, while always relevant to the individual in their own story and meaning-making, may originate in contexts that are more collective in nature (Measor, 1985; Webster & Mertova, 2007; Woods, 1993). Critical events may be "extrinsic" in that they are produced by historical and political events at-large (e.g., the 1969 Apollo 11 lunar landing or the global COVID-19 pandemic); they may be "intrinsic" as related to and occurring within the natural or typical progression of a career or lived trajectory (e.g., entering one's first year of teaching or experiencing the process of retirement); they may also be entirely personal and *only* relevant to the individual (e.g., a particular family event or dealing with illness). Critical events might also be bounded to a particular time or context—such as experiences occurring within a professional development program as is the case with the current study. No matter the origin, however, a personally relevant critical event can only be identified by the experiencer who has lived the event and knows the lessons from which he or she has carried away from the experience.

We contend that by attending closely to in situ experiences that teachers recall and reflect upon as most salient in their RET participation, we gain insight into teachers' shifting and emergent disciplinary understandings about science as a result of RET participation and, by proxy, identify aspects of the RET program that might be powerful for shaping such understandings. With this in mind, using a critical event narrative analysis, we ask: *How did one elementary teacher develop emergent disciplinary understandings about science in light of her firsthand participation in science research?*

3 Methods

This naturalistic case study takes a critical event narrative approach (Avraamidou, 2016; Webster & Mertova, 2007; Woods, 1993) to examine the experiences and shifting views of science of one elementary teacher, Ava (all names are pseudonyms) during her 6-week RET experience.

3.1 Research Context

The RET professional development program (which began in 1999) is held at a national interdisciplinary laboratory (the Lab) with over 600 scientific faculty and staff from science-related fields that include engineering, physics, biochemistry, chemistry, and materials research. The Lab is made up of smaller lab groups composed of research scientists, technicians, postdocs, graduate students, and occasionally undergraduate students participating in internships or undergraduate research experiences. The RET hosted in the Lab is designed to provide K-12 teachers with an opportunity to participate in cutting-edge scientific research within these smaller lab groups with the hope that these experiences will influence their classroom instruction (Enderle et al., 2014; Southerland et al., 2016; Davidson & Hughes, 2018).

The RET program is designed so that pairs of teachers work with a scientist mentor as part of that mentor's lab group for 6 weeks, and these pairings are decided by the program director based on teachers' science fields of interests as noted in their application materials. The teachers are selected by the program director so that (a) the summer cohort will have a combination of teachers from each grade band—elementary, middle, and high school—and (b) at least half of the selected teachers work in schools that primarily serve underrepresented and historically marginalized populations.

During the 6-week RET program, teachers spend the majority of their participation directly involved in research-related activities with their mentor scientist and others—such as lab assistants, graduate students, and postdocs—affiliated with their lab. The teachers are typically given explicit roles and responsibilities within their mentor scientist's lab and are active participants in the ongoing research. Participation for some participants includes, for example, preparing samples for experimental testing, reading and discussing background research, running experiments and collecting data, assisting with data analysis, helping in the writing of lab reports, troubleshooting and solving problems with equipment, and participating in lab group meetings.

While the structure of the RET program is designed so that the majority of participant time is spent engaged in active research work within science laboratories, the aims and goals of that work and the specific practices, procedures, and discussions teachers will have around their work with their mentor scientists and others can vary greatly. The program director selects mentor scientists that are typically known in the Lab to be open, patient, knowledgeable, and have a willingness to include teachers in their lab groups as full participants. This careful selection on the part of the director also typically allows teachers to feel supported by their mentor scientists and to have a more positive experience in the program (Davidson & Hughes, 2018; Hughes et al., 2012).

In addition to their daily research work, the teachers participate in regularly scheduled weekly meetings focused on science pedagogy and the nature of their research work at the Lab. These meetings include sessions around the inclusion of engineering or argumentation practices in the science classroom; teachers' sharing of favorite science lessons for feedback; and "lab crawls" in which pairs of teachers give a brief presentation about their research and take the cohort on a tour of their research lab. These sessions provide the teachers an opportunity to learn about one another's experiences at the Lab and serve as a shared space for camaraderie and commiseration in regards to teachers' research efforts. The final week of the program is dedicated to the preparation of a poster for the culminating research presentation session that occurred on the last day of the RET. Occasionally, teachers participate in other optional and non-research-related events—such as lectures from guest speakers, impromptu meetings with members from other research groups, or informal social gatherings occurring outside of the Lab.

3.2 Study Participant

This study draws on data from the 2017 cycle of the RET program. Ten teachers participated in the RET summer program, four of whom were elementary teachers. From the four elementary teachers, we selected Ava as the focal participant for this study because of her unusual tendency of conveying her epistemic insights about science. At the time of this study, Ava was a kindergarten teacher with an interest in science teaching and 18 years of teaching experience at the early elementary (K-3) level. She was working at a Title 1 school that predominantly served students from underrepresented populations who were also English language learners. Ava grew up in Puerto Rico where she attended university; she moved to the mainland of the USA after earning her degree in elementary education. She identified as a native Spanish speaker and described English as her second language. During this research experience, Ava was paired with another elementary teacher, Carrie, in a materials science laboratory, and both teachers worked with Dr. Ji, a mentor scientist who had been a scientist at the Lab for more than 10 years at the time of this study.

Because this study required a particularly reflective and articulate informant in order to explore shifts in disciplinary understandings through the lens of critical events, Ava was an ideal choice as a focal participant given her ability to deeply reflect upon and clearly articulate her new understandings about science in light of her RET experiences. Ava served as a key informant (Patton, 2002) in that she allowed us access to her thinking and experiences in ways that other participants did not, including, for example, her lab partner, Carrie. This informed our choice of focusing our analysis on Ava's experiences instead of Carrie who was overall less descriptive and articulate about her experiences at the Lab and more reserved in her explanations and reflections during interviews.

3.3 Data Sources

Multiple interviews conducted by the first author during and after the RET program served as the primary data source for this study. In addition, the first author conducted multiple observations of Ava, in her laboratory setting, in her work with other teachers throughout the program, and in her classroom in the months immediately following her RET participation. These observations served as secondary data sources, providing essential contextual information that allowed the researcher to ask additional questions about Ava's experiences in the program.

3.3.1 Semi-structured Interviews

Five semi-structured interviews were conducted with Ava during the program. These interviews typically consisted of eight-to-ten guiding questions and focused on multiple aspects of the RET experience including Ava's research project focus; her relationships with her mentor, teacher partner, and others at the Lab; her understandings about science; her feelings and emotions in the context of the research work; and other reflections on her experiences. Because the interviews took a semi-structured approach, the guiding questions for each interview were open in nature and included general questions about Ava's RET experiences (e.g., how would you describe your experiences so far in the RET program?; What is your mentor scientist like?; What is it like to work in your lab?) as well as her understandings of science as a discipline (e.g., what is science all about?; What do you think are the goals of science?; How would you describe what scientists do in their work?). Based on Ava's responses, the interviewer would then follow-up with more specific questions. All questions were asked in "plain language," free from technical jargon such as "epistemology" (Patton, 2002). Each interview lasted between 15 and 40 min and were audio-recorded and transcribed. The first interview took place during the first 2 days of the RET program, after Ava had met her mentor scientist, Dr. Ji. Following this, the next four interviews took place at fairly regular intervals of 1.5 weeks throughout the RET.

In addition to the observations and semi-structured interviews during the RET, the first author interviewed Ava again approximately 4 months after Ava's RET participation. The interviews occurred in Ava's kindergarten classroom at the end of 2 consecutive school days and were focused on Ava's reflections of her RET experience, her classroom instructional practices, and her understandings about the discipline of science. These interviews were more conversational in nature because the interviews took place primarily after school hours when Ava was not constrained by time requirements and because of the comfortability and relationship that was built over time between Ava and the first author. Both interviews lasted approximately 45 min and were audio-recorded and transcribed.

3.3.2 Direct Observations and Field Notes

In order to better identify critical events and resulting shifts in Ava's disciplinary understandings about science, the first author shadowed Ava through the program, conducting real-time observations and audio data collection during her research work two to four times per week over 6 weeks. Each observation was audio-recorded and lasted between 20 min and 2 and a half hours. Field notes were also taken during each observation (Patton, 2002) to create rich descriptions of interesting moments of activity, interaction, and/or discussion within participants' lab groups including direct quotations. As such, the field notes and direct observations were essential for informing the first author's interview questions for Ava. Additionally, these field notes and audio-recordings were used as a secondary data source for triangulation and, when possible, to develop richer understandings of the critical events that Ava described in interviews. In total, over 30 h of naturalistic observations and corresponding audio-recordings and field notes were collected.

3.4 Data Analysis

This work takes a critical event narrative approach to data analysis. The three events classified as "critical" in this study were identified based on the assumptive criteria of critical event analysis as described by Avraamidou (2016) and Webster and Mertova (2007). For the first phase of analysis, the first author read through all transcripts from the classroom interview data set to (1) identify references to particular events that might emerge as "critical" with further analysis and (2) note the ways in which Ava described aspects of her disciplinary understandings about science. The classroom interview set was chosen for the first pass because of its temporal distance from Ava's RET participation, since the classroom interviews occurred several months after the conclusion of the program. This is in line with critical event analysis which notes that the more time that has passed between an event and recall of the event, the more impactful it may be considered (Webster & Mertova, 2007).

Once events were identified within the classroom interview data set, the first author read through the rest of Ava's interview transcripts in chronological order (from earliest occurring week 1 to most recent occurring week 6) to cross-reference those mentions of events with Ava's discussions of them during the RET. To be considered a critical event for this study, the event in question needed repeated mention (at least four times) across both interview data sets (the classroom set and the RET set), and Ava must have shared a reflection, description, or comment about her understanding about the discipline of science in relation to the event.

From these criteria and the process of cross-referencing events between the two data sets, three events were identified as "critical": (1) "The Composite Image Puzzle," (2) "Lessons Learned from Dr. LG," and (3) "Meeting Real and Accessible People." These events, which will be discussed further in the findings, stood out because of their saliency to Ava both during and after the RET and their correlation to Ava's shifts in her understandings about science. Once these events were identified, we carefully examined how Ava described her understandings about science in relation to these events to develop an account for how these events acted as catalysts for shifts in Ava's understandings. Evidence of shifts were identified through discursive indicators that marked some change in ideas (e.g., "I never thought of it like that before") or presented a juxtaposition of ideas that may have been held in competition with one another (e.g., "he is a genius" and "he is just a person" when talking about a particular scientist). Such instances were cross-referenced in both interview data sets. When possible, field notes and audio-records were examined to gain more insight into the context, setting, and other participants in the event.

3.5 Trustworthiness and the Position of the Researcher

As a member of the RET program support staff, the first author held an "insider" position as a researcher in this study. Having worked as support staff for this particular RET program for more than 3 years, she was familiar with the Lab community and context, as well as the programmatic structure and elements of the program. The first author was responsible for collecting data, conducting interviews and focus groups with participants, leading participants in pedagogy workshops, and acting as assistant to the program director. The first author had no directorial or supervisory role toward teacher cohorts but instead was positioned as a "resource person" and "curious researcher" by other staff and scientists in the Lab, a distinction that was made explicit to teachers each year.

The first author and Ava established a friendly association early on which was maintained during all points of data collection. Throughout the 6-week RET, the first author was a constant presence for Ava and other participants; she was present at orientation, afternoon sessions, in and out of research laboratories, attended several social gatherings, and made herself available to talk with teacher participants whenever questions or concerns arose during their experience. This consistency of visibility and availability allowed her to develop rapport and establish trust with those in the RET cohorts, overall, and to continue to develop a safe working relationship with Ava, specifically. This familiarity and trust likely furthered Ava's willingness to share openly and honestly about her experiences.

From this perspective, the relationship between the first author and Ava can be considered to be an asset to this work as it has allowed for a depth of access to Ava's thinking, experiences, and reflections. However, such closeness to the data and the participant may create bias in interpretation if not held in check. Therefore, various measures were taken to ensure trustworthiness of the analysis (Guba, 1981; Shenton, 2004). First, the primary interview data sources were cross-referenced and triangulated with observational data and field notes to ensure consistency across data sources. Additionally, analytical memos and raw data were shared with the co-authors as external researchers not affiliated with the Lab in order to discuss and negotiate possible alternative interpretations regarding the findings and in turn reduce bias. Most importantly, Ava has had opportunity to review the findings and found the interpretations of her experiences and disciplinary understandings about science to be accurately accounted for.

4 Findings

Based on an analysis of Ava's reflections and descriptions of her research experience at the Lab, three critical events were identified as having a lasting impact on Ava's disciplinary understandings about science: (1) "The Composite Image Puzzle," (2) "Lessons Learned from Dr. LG," and (3) "Meeting Real and Accessible People." Close examination of Ava's reflections on these events allowed the research team to identify shifts in her disciplinary understandings of science. Below, we begin with a brief description of each critical event; and then, we discuss the shifts in Ava's understandings of science as described by her in the post-RET interviews in light of each event. Afterwards, we examine instances within her 6 weeks at the RET in which Ava referred to this event and her understanding of science as related to it. Lastly, we explore how shifts in Ava's disciplinary understandings about science in light of the critical event were consequential to her orientations toward her teaching.

4.1 Critical Event 1: the Composite Image Puzzle

During her time in Dr. Ji's laboratory, Ava was involved in his ongoing research work around superconducting materials. Specifically, Dr. Ji and his research team were investigating how different cooling rates will affect the structural integrity of a certain type of high-temperature superconducting metal that has been bundled in a wire formation and coated with a silver magnesium sheath. After heating samples of the wire to more than 850 °C, Dr. Ji's team would slowly cool the samples at varying rates in order to determine how the cooling might influence the structure of the wire; once the wires were cooled, they were cross-sectioned and examined under a high-powered scanning electron microscope (SEM) for analysis.

While this was the "big picture" of Ava's research context, her participation involved a number of activities, including preparing wire samples for the furnace and the SEM, collecting data from experimental trials in the form of "checking in on" the furnace and the slow-cool rates from time to time, using the SEM with guidance from Dr. Ji to take images of the wires, and using computer programs to run computation data analysis and to create composite images of wire samples taken from the SEM. This last activity provides the context for this critical event.

In this event which occurred early on in the RET program (week 2 to day 2), Ava and two other members of her research team—her RET teacher peer, Carrie, and a graduate student who was new to the Lab, Kevin—struggled to create a single composite microscope image of a wire sample cross-section from many individual image files using a photo imaging computer program. This team spent more than 40 min engaged in a trial-and-error style troubleshooting approach to solving the problem but was unsuccessful at each pass. While Dr. Ji had given them an overview of written procedural steps and had previously demonstrated creating a composite image on the software, all three were stumped by the problem. They could not figure out why the image would emerge jumbled rather than as a single composite at each attempt. Eventually, after much frustration and many failed attempts, Dr. Ji returned to the Lab and offered the missing information that seemed to solve the composite issue.

From a researcher perspective, this episode did not seem particularly interesting or important when observed in real time. However, to Ava this episode became critical to her understanding of science in that she repeatedly called upon her memories of this experience to describe her realization that science is replete with puzzles and complexities and to describe the importance of scientists' perseverance through trials and errors. These two realizations were evidenced not only in Ava's RET interviews with the first author and her exchanges with others during the RET, but also when she recalled this event more than 3 months after the RET program during the researcher's visit to her classroom.

4.1.1 "Puzzles" and Complexities as Inherent to Scientific Work

For Ava, the Composite Image Puzzle event helped her recognize that puzzles—or problems to figure out and solve—are an inherent part of doing science. In her reflective interviews post-RET, she thought back on her firsthand experiences with what she called "a puzzle" in light of this event:

> When we worked on the sample image—you remember?—The computer and all the separate pictures together, Oh my God! It was a puzzle!-- and we had so, so, so much trouble, I still can't believe how crazy that was to me – we had to keep trying and try a different way and try another way and it didn't work at all. Then later on when Dr. Ji came, he just did it. [Semi-structured interview, classroom visit day 1]

Ava's recollections portray the sense of frustration and vexation that she experienced as she and her team attempted to resolve this "puzzle" and her firsthand experience of the complexity of scientists' work, even with something seemingly as simple as creating an image.

During the RET itself, there was evidence of the emergence of such understandings as Ava referenced this critical event later in the week of its occurrence, noting her surprise at the amount of effort and work needed to create the composite image of the sample. In this reflection, she recognized that even though sample preparation might seem "simple" and procedural, it is an important, difficult work:

> I tell you, I could not believe how hard we had to think to do something so simple – well, it's not simple – we didn't know how to do it! But you have to practice and try and try and try, you have to see it as a challenge and you have to—I don't know—even though it's just a photo that we're making—it's something that will help Dr. Ji and others understand something new about the [sample material]. I never thought about [science] like that before – so many people have to do work that might look simple, but it's not really and it has to get done for something big to happen or be discovered or something like that. [Semi-structured interview, week 2–day 4]

Indeed, in order for scientists to create new knowledge, data must be translated from raw form into something useful for analysis and—despite the potential "simplicity" of this task in some contexts such as this—Ava's reflection highlights that such procedural work is often times both critical and complex for scientists. From this standpoint, Ava and the research team were engaging in this important pre-analysis work in their attempts to create the composite image. Having this firsthand experience allowed Ava to consider the complex and puzzling nature of science in ways that she had "never thought about" before.

4.1.2 Perseverance Through Mistakes and Trial-and-Error

Related to Ava's understanding of "puzzles" and complexities as an everyday aspect of science, another important shift in Ava's disciplinary understandings comes in the form of an emergent recognition of the necessity for perseverance through mistakes and trial-and-error approaches to problem-solving in science. In recalling the "Composite Image Puzzle" event, Ava described what her mentor said about mistakes: that they happen "all the time." As Ava reflected:

> After he came into the Lab and helped us complete the composite image, Dr. Ji] said, 'I had to learn and try, too, and make many mistakes.' He said he makes mistakes all the time. And I was like, YOU?! Wow. [Semi-structured interview, classroom visit day 1]

This move on the part of Dr. Ji to normalize and persevere through mistakes and trial-and-error was taken up by Ava in an impactful manner. This event shifted not only her understanding of science, but also the ways in which she began discussing science with her students in her own classroom:

> So now, I tell my students, too, mistakes are okay. We all make mistakes, even teachers, even scientists. That's part of learning, I think. Don't you think? You have to keep trying. [Semi-structured interview, classroom visit day 1]

That she felt a new compulsion to share with her students that "mistakes are okay" gives a glimpse on how this shift in Ava's understanding of science influenced her classroom instruction as she became more intentional about normalizing mistakes as part of doing science.

4.2 Critical Event 2: Lessons Learned From Dr. LG

Another event identified as critical for Ava's understandings about science occurred later in the RET program (week 5 to day 2) when a prominent researcher in the physics community and a lead scientist at the Lab, Dr. LG, gave a talk for visiting undergraduate and graduate researchers at the Lab. In addition to her presentation about her personal work in physics and a brief overview of the history of the development of superconductivity theory, Dr. LG also discussed the importance of diversity in science, how global and local political and social structures can influence scientific research, and how understandings of new ideas—particularly in new fields of study—take a long time within the scientific community. The RET participants were not expected to attend this talk; however, Ava had heard about the talk from a visiting undergraduate and decided under her own volition to attend. When asked about "a favorite memory" from her RET experience during the first author's classroom visit, this event immediately came to mind for Ava. The resulting shifts in disciplinary understandings that she described that were tied to this critical event include her realization that science occurs within complex global and sociopolitical contexts and a recognition of the importance of diversity of both people and perspectives in scientific endeavors, as we discuss below.

4.2.1 Science Occurs Within Global and Sociopolitical Contexts

As part of her talk, Dr. LG described how the production and supply chain of liquid helium—a substance critical to maintaining the extremely low temperatures necessary for superconductive states in some materials—had been interrupted in some Middle Eastern countries because of political disputes in the region. The helium shortage had serious consequences for nuclear magnetic resonance and superconductor research worldwide. Referencing this part of Dr. LG's talk, Ava pointed out that she had new understandings of how science and geopolitics are related. As she shared that many of her new students had only recently come to the USA from Puerto Rico because of the extreme devastation caused by Hurricane Maria in 2017, Ava noted:

> You know, so many of my students are new right now because of [Hurricane] Maria – they're in a new city, new school, they only speak Spanish—but that's okay, I speak Spanish. But it breaks my heart and, you know, [Puerto Rico is] my country—and the destruction—these hurricanes aren't going to stop. I mean, I think [about] climate change, but politics right now--I don't know if scientists are studying—I mean I know they're studying but—I never thought how politics—you know, how [do political decisions and politicians] decide what [scientists are able] to research? I don't know. Remember when I was talking to you about the professor and her talk at the Lab? Remember she talked about the gas and the Middle East and how science was having trouble doing research because of the politics [in the region]? I see it differently than before—like connected—and maybe [politicians] think they can decide what to believe in science or something. [Semi-structured interview, classroom visit day 2]

While the connections between hurricanes, climate change, and liquid helium production may seem tenuous, Ava's reflection on the related nature of scientific work and the global and political structures that influence such work comes through soundly as she considers both Dr. LG's commentary on stalled progress in superconducting science due to political strife and the circumstances of her displaced students from Puerto Rico who have experienced a catastrophic weather event. Importantly, Ava's reflection points to a shift in understanding as she notes seeing science "differently than before" in that it is "connected" within global, political, and societal structures. Moreover, Ava recognized how these contexts can influence the livelihoods of people at the individual level, whether scientists attempting to conduct research or students whose families have been affected by politicians as they decide whether to "believe" or accept evidence for controversial issues such as climate change.

4.2.2 Importance of Diversity of People and Perspectives in Science

Another shift in Ava's disciplinary understandings of science resulting from Dr. LG's talk was her emergent understanding that diversity is essential in science—not only in terms of diversity of people and their cultural backgrounds, but also in terms of the diversity of perspectives that serve to strengthen the construction of explanations through critique and argumentation in science. In reflecting on Dr. LG's statements about diversity in science, Ava stated:

> It's so important to me that others heard [what Dr. LG shared about diversity in science] – that I heard that. Science—it's for everybody, you know? I think scientists have different personalities that makes what everybody cares about in the research maybe a little different. You know, the social aspects or—but science, I don't know. It's not only one way. I looked at [Dr. LG] and she is a scientist, and she talked about diversity, and she's a woman, too. What she said was so awesome […] that many different ideas contribute to better science. That each person can see something different and make [the research] better than just one [scientist] doing it alone. [Semi-structured interview, classroom visit day 2]

In this comment, Ava reflects on the importance of diversity in science, not only from an equity lens, but also from an epistemological standpoint of strengthening knowledge construction through diverse ideas and approaches. She also notes that differences in "personality.

or perspective can shape the scope and interpretations of research in science. This same sentiment came up for Ava in an interview during the RET where she expanded on her lessons learned from Dr. LG's talk in connection to her students' experiences in the science classroom:

> At the beginning [of RET] in orientation, [the RET director] said, 'At this Lab, there are people from all over the world working here' and to me, that's fascinating!! Because that's science. Like Dr. LG was saying, science is global and you have to have an open mind to other's ideas. Even in your classroom, you have to have an open mind. My classroom is always diverse—every year—Spanish speakers, kids from Haitian communities, a lot of my students don't have a lot and they don't always know how to share their ideas—but they have good ideas and they learn how to work together. It's like [Dr. LG] was saying, science is diverse. I didn't think about it before in that way, but she's right—People from many parts of the world are here [at the Lab] contributing to many discoveries together. [Semi-structured interview, week 5–day 4]

Here, Ava described the need to have "an open mind" to the ideas of others and draws on Dr. LG's talk to consider the students in her own classroom and their positions as diverse learners. Her shifting understanding about science regarding the importance of many people from "all over the world" working together to further research parallels the ways in which Ava comes to view the learners in her classroom as capable thinkers with "good ideas" who are able to collaboratively work together even though they are quite different from one another.

4.3 Critical Event 3: Meeting Scientists at the Lab

One event that Ava continually reflected upon during post-RET interviews was in reality a collection of smaller critical events rather than a singularity: meeting individual scientists and getting to know them. We chose to present this as a composite, singular critical event because of the ways in which Ava consistently referred to these encounters as if they were one event, often referencing multiple people in the same reflective moment to make illustrative points about how important these meetings were to her. Shifts in Ava's disciplinary understandings about science that occurred as a result of meeting scientists at the Lab include a realization that scientists are "real and accessible" people and that scientists were once students in K-12 classrooms.

4.3.1 Scientists as "Real and Accessible" People

When asked during the first researcher's classroom visit to share her motivations for participating in the RET program, Ava noted:

> You know me, I love people. So, to me, science is people, right?—trying to figure things out about—about the world, about nature, the physics. At least I think. That

> was part of my purpose in coming [to RET]—to meet scientists. To meet them as real and accessible people. Because, you know, my days in school—every day is structured and I have to do things a certain way at certain times, but at the Lab […] I got to take every opportunity that appeared to meet people and to know about all the things going on at the Lab and what the scientists do and, you know, who they are. I really wanted to know who they are. [Semi-structured interview, classroom visit day 2]

Ava's description of scientists as "real and accessible" demonstrates a shift in her thinking from previous descriptions of scientists early on in the RET program. During the first day of the RET after meeting her mentor, Dr. Ji, and talking to him for the first time about the research work for the summer, Ava shared this aside with the first author:

> I think Dr. Ji is so sweet, but you can just tell he is a genius and it's all about the science. I don't think he knows how to explain to people that don't already know about the research. But scientists are just like that, no? [Informal conversation, week 1 to day 1]

In this excerpt, there is a sharp contrast between Ava's initial generalization that "scientists are just" genius-like and do not know how to talk to laypeople about their work and her later views of scientists as "real and accessible." This shift began to take form early on in her RET experience, starting with her developing relationship with Dr. Ji. When asked during one of the interviews during the first week of the RET to describe what it is like to work with her mentor, Ava shared this reflection:

> He's so helpful and patient, but he's a genius. He's a super smart person – and not just with science. We were talking about politics in my country [Puerto Rico] and he knew everything about the [debt] crisis—I was shocked because unless you are a local—I don't know—there are things people don't know about and he knew about it! He surprised me. He's so smart about his work, but he knows about what's going on in the world, too and that surprised me a lot. I don't know why—I think you just think it's going to be all about the science work only with someone so brilliant. [Semi-structured interview, week 1–day 4]

At first, Ava was caught off guard at Dr. Ji's knowledge of the current events in Puerto Rico because of her expectation that scientists' interests and knowledge might only be "about the science work only." But Ava's notion that someone like Dr. Ji would only be interested in his research was challenged by their discussion of the political and economic situations of Puerto Rico—a topic of specific importance to Ava given her strong cultural and familial ties.

In another reflection of her encounters with scientists, Ava describes two younger graduate students she met at the lab—Gladiola and John:

> I'm very fascinated by people and their lives. For like, Gladiola—she is a young African woman that—she's a scientist. She's doing her [graduate] studies here at the Lab and she's been to Russia and speaks Russian and she has so many stories and experiences from Russia and Nigeria and now here. And John—he's from Wisconsin I think—he's been showing me how to use the machines and the different polishing with the [fine-grained polishing] paper. He is trying to figure out if he likes science enough to stay in science, but he also plays music and we talk about his dog and he's a person. [Semi-structured interview, week 3–day 5]

Here, Ava is expressing her developing understanding that scientists' lived experiences include not only their academic or professional research endeavors but also their personal lives and interests. She describes Gladiola and John in ways that demark their belonging to the scientific community (as a graduate student and scientist, as a technician using the sample polishing machinery) and also highlights her knowledge of their interests and experiences that may be outside of science, such as speaking multiple languages and traveling internationally, playing music, and having a dog.

Echoing a similar sentiment, when asked to describe what she would likely take away from her participation in the program toward the end of her RET experience, Ava noted:

> The experience [of RET participation] has been a great experience for me. It will last my whole life. I'm not afraid of science or scientific people. I used to be, I think—you know, intimidated or really afraid because they're so, so smart—brilliant. But meeting scientists and getting to know them—like Gladiola and John, Dr. Ji—about their families and pets and kids, their countries, what they like to do—there's so much more than science. I think I used to think, oh scientists are just—you know, like only geniuses. Do you know what I mean? But they're just people, too. [Semi-structured interview, week 6–day 2]

Encountering scientists "as people" demystified them for Ava and, in turn, shaped her views of who scientists are and who they can be: that they are more than "just" geniuses, but are also "real and accessible" people with varied knowledge, interests, and experiences.

4.3.2 Scientists Were Once K-12 Students

Related to this shift in understanding that scientists are people with diverse backgrounds, interests, and experiences, Ava had an eye-opening realization relating to her getting to know scientists at the Lab. For Ava, coming to see scientists as "real people" allowed her to understand that all scientists have not always been scientists—rather they were also K-12 students at one time before pursuing their research trajectories:

> I just loved meeting all the scientific people. Because I love people. Like Gladiola—Remember? And Kevin and—do you remember John? And Charlie—Charlie was the one from Colombia in the lab and, oh my God, I remember he said to me, 'my third-grade teacher made me love science.' I learned something—That really stuck with me because my third-grade teacher in Puerto Rico—she loved teaching us science. And it made me think—everyone I met at the Lab. Every scientist—they had teachers. They had high school, middle school, third grade—and kindergarten too, right? [Semi-structured interview, classroom visit day 2]
>
> She continued:
>
> You know, other teachers [at this school], they don't really teach science every day. It's not a priority [within the school or the team]. But I teach it every day. Every single day. Because, you know what? Because John and Charlie. Because Gladiola, Kevin, Dr. Ji– they all had kindergarten teachers—you know, they learned to love science somewhere maybe—maybe not kindergarten but still. It's my responsibility to share with my students—to teach science. To help them love it. [My students] could do it—they might be like John or Charlie someday. I take that so seriously. Very seriously. [Semi-structured interview, classroom visit day 2]

That Ava describes feeling the "responsibility to teach science" "every single day" in relation to her encounters with scientists at the Lab is powerful. For Ava, her realization that scientists were once K-12 students had a profound impact on her prioritizing science in her teaching and compelled her to view her own students as potential scientists of the future.

5 Conclusion and Implications

In this research, we set out to explore shifts in one elementary teacher's understandings about science in light of critical events that occurred during her participation in a six6-week research-intensive professional development program. We identified three critical events—The Composite Image Puzzle, Lessons Learned from Dr. LG, and Meeting Real and Accessible People—that were particularly salient in shifting Ava's disciplinary understandings about science. While other events—both from her RET experience and otherwise—may have had important roles in influencing Ava's views of science as a discipline, we chose to focus on these particular events because of their enduring importance to Ava even several months after her RET participation and because of the ways in which she carefully and clearly articulated shifts in her understandings about science in light of these events.

To our knowledge, this is the first study to closely examine shifts in disciplinary understandings about science through the lens of critical events in an RET program. Ava herself did much of the reflective work that marked these events as critical as she recalled these experiences and connected them to her understandings of science without overly specific prompting during interviews. By taking Ava's perspective seriously and carefully examining the ways in which she draws upon these critical events, we were able to understand *how* Ava's RET experiences engendered nuanced understanding about specific aspects of science, scientists, and the work that they do. In what follows, we discuss the noted shifts in Ava's understanding about science as connected to the critical events and their implications to her science instruction. We also discuss the contributions of this work in terms of methodological and design considerations for professional development programs such as RET or those that position teachers as "doers" of science.

5.1 Discussion

A primary goal of the RET program at the center of this study is to support teachers to develop more robust understandings of science through immersive and collaborative research participation with the aim of influencing their classroom instruction in productive ways. To this end, we argue that taking a critical event analysis approach allowed us to see how aspects of this goal were met for Ava in ways that perhaps a more traditional methodological approach would not have captured. Related to each of the critical events described in the findings, Ava came to experience shifts in her understandings about science, shifts toward understandings that resonate with those held by the fields of history, philosophy, and sociology of science, as well as science education. While her insights are not new to these fields, they were new to Ava and held important implications for how she came to view aspects of the discipline and how she came to orient to her students as capable thinkers and doers of science as we discuss in this section.

In light of the "Composite Image Puzzle" event, Ava began to understand the prevalence of puzzles and mistakes in scientific research, as well as the need for scientists to develop a stance of perseverance as they navigate uncertainty in their work. Certainly, procedural error, flaws in experimental design, equipment difficulties, and ambiguous or confounding anomalies in data all might create opportunities for scientists to wrestle with “a puzzle” in their research in similar ways that Ava experienced as she and her colleagues attempted and repeatedly failed to create the composite image (Allchin, 2012; García-Carmona & Acevedo-Díaz, 2018). These opportunities to problem-solve in science—when framed in productive ways—might be seen as chances to develop perseverance and tenacity in the work (Pickering, 1995) for scientists in their endeavors, for teachers in their research participation, and in turn, for students in their classroom science learning (Davidson et al., 2020; Manz & Suarez, 2018).

While Ava and her team were unsuccessful in solving the puzzle of the composite image, their efforts were still acknowledged, their mistakes and frustration normalized, and their perseverance praised by Dr. Ji who shared his own stories of struggle when ambiguities in his work have created puzzling conundrums to push through. Dr. Ji’s work to normalize aspects of the “puzzle” event echoes the findings of Hughes and colleagues (Hughes et al., 2012) who note that teachers who work with supportive, hands-on mentors are more likely to come away with nuanced understandings about science.

Learning to normalize ambiguity, frustration, and perseverance as essential aspects of doing science became important to the ways in which Ava oriented to her classroom teaching. After the RET program, Ava described how she wants to help her students see “mistakes” as part of learning something new. Teachers may be concerned about allowing students to experience uncertainty in science or to grapple with “puzzles” that arise in investigations, yet these are part and parcel to the work of scientists. As such, students need opportunities to encounter them in the science classroom.

In light of the “Lessons Learned from Dr. LG” critical event, Ava came to understand that the scientific community is situated within sociopolitical contexts that influence how scientific research is conducted (Dagher & Erduran, 2016; Longino, 2002; Pickering, 1992) and came to see the importance of diversity for the development of science. Global and sociopolitical contextual factors are important to take into consideration when accounting for how scientists come to decide the lines of research to be pursued and how such research is carried out. That Ava connects these realizations to her students’ experiences through the lens of politics and climate change suggests her broadening understandings about science to include the notion that individuals are impacted by the ways in which political structures take up or reject scientific research.

Along with these lessons, Ava also recognized that the scientific community can be—and more importantly, should be—diverse and such diversity brings with it different perspectives. Ava relates this idea of diversity to her goal of having her students work together and share ideas in the classroom. However, more than this, the diversity of perspectives is a critical aspect of scientific research if scientists are to hold themselves to the regulatory ideal of “strong objectivity” in scientific knowledge production (Harding, 1992; Keller, 1992; Longino, 2002). As scientists are—to quote Ava—“just people,” they bring with them their personal backgrounds, experiences, cultures, race, gender, sexual orientations, and any number of other factors associated with one’s identity, and these serve to shape the lenses with which they view and interpret their research. Many perspectives on the same data sets may yield different interpretations of said data, which lead to discussion and critique within the community and, in turn, allow for more robust understandings through the social construction of knowledge (Harding, 1992; Longino, 2002). In this way, diversity is not only an important issue of equity and access in science, but also an epistemological imperative. As Ava comes to understand this notion, she begins to orient to her kindergarten students as collaborative and capable thinkers in science who bring a diversity of experiences, knowledge, and cultural backgrounds to the classroom. In the same way that science in a laboratory or field setting is enriched by the diversity of perspectives and experiences, science learning in the classroom is enriched by students' diverse resources.

Related to this notion of diversity in science, Ava's encounters at the Lab with multiple scientists from varied backgrounds allowed her to shift her generalized view of scientists as brilliant geniuses unable to communicate their work to non-scientists toward seeing scientists as relatable people with diverse interests and experiences within and outside of science. Indeed, scientists are people with a full cadre of experiences and viewpoints about the world, and—as Ava observes—scientists were once young students in a science classroom. To her, this has important implications for her own classroom practice as she views her own kindergarten students as potential future scientists, a view that compels her to teach science every day even when others around her do not have this same priority.

Research suggests that opportunities to learn science are often overlooked in early childhood and elementary science classrooms, yet these contexts are also often the first opportunities students will have to cultivate positive attitudes toward science and to have their curiosities about the natural world piqued and affirmed (Banilower et al., 2013; Czerniak & Mentzer, 2013; Gopnik, 2012; Grinell & Rabin, 2017; Mantzicopoulos et al., 2008). From this view, it is no small thing that Ava has taken seriously the responsibility of teaching her students science every day and internalized this responsibility as a result of getting to know scientists at the Lab.

5.2 Methodological and Design Implications for Teacher Education Programs

This work is predicated on the notion that an essential aspect to supporting teacher learning is taking teachers' own experiences and meaning-making seriously. It is important to recognize that teachers—as individuals with their own prior experiences, worldviews, and predispositions—enter professional development spaces such as RET with their whole selves in tow and not just their "teaching selves (Blanchard et al., 2009). From this lens, we acknowledge that Ava's typically positive attitude and upbeat demeanor, her self-identification as someone who "loves people," and her willingness to attend optional activities such as Dr. LG's lecture are a few examples of inclinations that likely had noteworthy impact in determining what Ava would participate in and do during the RET, and in turn, what she would come to see as salient to her learning about science. For another teacher, it is likely that a critical event analysis would highlight very different critical experiences and, therefore, different lessons learned.

In light of this consideration, we argue that an important contribution of this work is methodological in nature. This study is exploratory in terms of examining what a critical event analysis methodology might afford researchers to understand about teacher experiences in professional development contexts such as RET; taking a critical event analysis approach allowed us to see one teacher's learning in ways that have not been previously captured. We argue that it is necessary to attend to teachers' interpretations of critical experiences and events that have *personal relevance to them* in order to better understand and support their learning in professional development experiences—particularly when the aims of such experiences are to challenge teachers' assumptions or understandings of the discipline. Accordingly, we examined the shifts in disciplinary understandings that became salient for one elementary teacher through the lens of three critical events to which these understandings were deeply tied. However, while the specific critical events identified as most salient for Ava's disciplinary understandings were individual and personal to her, the *kinds* of experiences that shaped her understandings have potential to be more universal and accessible to all teachers through RET participation with thoughtful planning on the part of professional development programmers.

For example, including opportunities for teachers in RET to experience "puzzles" in scientific work and to wrestle with uncertainty may be an important step in helping teachers to understand that it is normal for practitioners of science to experience vexation and frustration in research (Davidson et al., 2020). Teachers who understand these aspects of the discipline of science may be in a better position to plan for and leverage moments of uncertainty as they support students' science learning in the classroom. As such, developers of teacher research experiences might explicitly design and plan for opportunities that allow teachers to experience, recognize, and discuss productive struggle and perseverance as aspects of science and, in turn, support teachers in translating these ideas toward their classroom instructional practices (Ford, 2008; García-Carmona & Acevedo-Díaz, 2018; Kelly, 2018; Manz, 2015; Manz & Suarez, 2018). As mentioned before, Ava's feelings of frustration and her "puzzlement" in light of the "puzzle" event were normalized by Dr. Ji which allowed her to internalize those experiences as part and parcel of doing science. It is then important to examine how scientist mentors in research experiences support teachers to normalize struggle in science (Hughes et al., 2012) and to design ways within RET programs to help teachers understand the affective and epistemic learning that takes place when uncertainty arises.

Additionally, it is important for researchers and program developers to plan time and space for teachers to interact with scientists on a regular basis. Indeed, learning to see scientists as more than geniuses but as "real people" may not have been so powerful for Ava had she *only* been interacting with Dr. Ji throughout here RET research experience, instead she interacted with a wide range of scientists. Through this, Ava came to understand scientists as "real and accessible" people with diverse experiences and backgrounds that they leverage to strengthen their research because of the opportunities for social and professional interactions with many different people working across the larger Lab setting. These interactions, which became a critical part of Ava's experience and learning, may not have happened as frequently or been held with such importance had she not been granted agency to interact with others in the Lab. The Author(s) blinded for review (2016c) have noted the critical importance of social interaction in RET for teachers in terms of changing their beliefs, practices, and knowledge around science and science teaching. Moreover, the development of relationships with multiple scientists and her choice to attend Dr. LG's lecture afforded Ava opportunities to reflect on her own students. This allowed her to come to view them as potential future scientists with diverse backgrounds and experiences who are capable of thoughtfully reasoning and collaborating with one another in the science classroom.

While not directly related to the programmatic features of the RET, Ava was given explicit opportunities to reflect upon, connect, and unpack her laboratory research and other experiences at the Lab during interviews. From these explicit reflections, we were able to identify emergent and shifting views of Ava's understandings about science that seemed more aligned with a vision of science as outlined in current science education reform efforts (NGSS Lead States, 2013; NRC, 2012). Approaching this work from a critical event lens allowed us to (a) capture aspects of the RET experiences that held particular importance for Ava and (b) examine how these events shaped her understanding of science. This was made possible through the various opportunities that Ava had to share and reflect on her own RET experiences. With this in mind, we argue that it is critical for researchers and program developers to engage teachers in explicit and reflective discussions on their experiences within scientific research and to build in time during professional development to build trust and rapport with participants and to allow for these kinds of rich discussions. Such opportunities may support teachers to develop nuanced and productive understandings about science as a discipline—in terms of both their understandings related to science epistemology and understandings about the nature of scientists and their practice.

In sum, this work suggests that it is necessary for researchers, program developers, and other stakeholders to take seriously the perspectives of teachers in light of their research experiences. To do so, it is important to provide teachers spaces for reflecting on and discussing their disciplinary understandings, to plan for and leverage opportunities for uncertainty in productive ways, to allow agency and choice over aspects of teachers' program participation, and to provide opportunities for social interaction between teachers and scientists. These considerations might allow teachers to develop refined understandings about science, which in turn could productively translate into their teaching and learning in the science classroom.

5.3 Limitations and Future Research

This work focused solely on one teacher's developing views of science through the lens of critical events that occurred during her participation in research. However, there are several limitations to the study. While only three events were identified from the data sets as "critical" (Avraamidou, 2016; Webster & Mertova, 2007), it is likely that other events that influenced Ava's understandings about science were not captured in this study. Additionally, it is worth noting that some activities—Dr. LG's guest lecture, for example—were quite specific in nature and may not be a mainstay of every RET iteration. This means that some experiences and opportunities for teacher learning in programs such as RET may vary from year-to-year. Future research endeavors should consider the potential of consecutive years of participation in research-based professional development such as RET, as well as how experiences and opportunities for learning may differ across years, and the ways in which teachers' disciplinary understandings begin to shift and take shape over time through multiple interactions within the community of science as peripheral novice participants (Davidson & Hughes, 2018).

Relatedly, we recognize that critical event analysis is only one way to approach examining teachers' understandings and learning in a professional development context such as RET, and this approach may not capture all lessons learned or shifts in understandings for participants. Indeed, there may be new or shifting ideas that teachers hold as a result of their RET participation that are less obvious, less salient, or invisible to researchers through the lens of critical events but nonetheless have an impact on teacher attitudes, understandings, and classroom practice. Additionally, it is possible that within cases, participants might describe shifts in their understandings that are not specifically tied to particular events or experiences—that is, for some participants, a critical event analysis would be less revealing than taking another methodological approach. With this said, we maintain that the shifts in Ava's disciplinary understandings of science articulated in the findings resonate with the critical event analysis approach and are clear and cogent within the data. Nonetheless, it is important for the field to continue the work of examining teacher change in professional development such as RET and to approach this examination from a multitude of directions—including that of critical event analysis, which—in Ava's case—allowed for the illumination of novel links between her experiences and her learning. Likewise, while this study takes a single-case study approach to understand one teacher's learning in relation to particular events that were important to her, we see potential for more expansive approaches to the use of critical event analysis for understanding how groups of teachers may think, feel, and learn in relation to collectively experienced events in professional learning settings.

Another consideration of this work recognizes that some of the shifts in Ava's disciplinary understandings may have resulted from the reflective work that she engaged in during interviews as a result of the researcher's questioning and pressing for reflection instead of directly emerging from specific research experiences. However, we see this as less of a limitation and more of an inherent aspect of qualitative research work. In fact, as we note in the implications section, we also consider this aspect of our findings as motivating the need to embed such reflective opportunities within RET and other professional development programs.

Finally, this present study does not explicitly examine the ways in which Ava's disciplinary understandings about science manifested in her classroom instructional practice in action, specifically in terms of her instructional planning and enactment. Instead, we touch upon the ways in which Ava described connections between her disciplinary understandings of science and her orientations toward her students and her classroom, which can be an important first step in shaping instructional practice. It is essential that future research examines how teachers' disciplinary understandings about science as a result of science research experiences may shape classroom practices in action if the field is to more fully understand the role of RETs and critical events as catalysts for teacher learning and, in turn, science teaching.

Author Contribution All authors contributed to the study conception and design. Data collection and initial analysis were performed by Shannon G. Davidson; subsequent rounds of analysis and refinement were performed by all authors. The first draft of the manuscript was written by Shannon G. Davidson, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Code Availability Not applicable.

Declarations

Ethics Approval The authors obtained approval for this study from the Florida State University Office of Human Subjects Protection and the Institutional Review Board.

Consent to Participate Informed consent was obtained from all participants involved in this study in accordance with the Florida State University Office of Human Subjects Protection and the Institutional Review Board.

Consent for Publication Pending acceptance of the manuscript, the authors give consent for publication in *Science & Education*.

Conflict of Interest The authors declare that they have no conflict of interest.

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