RESEARCH ARTICLE

JRST | WILEY

Science teachers in research labs: Expanding conceptions of social dialogic dimensions of scientific argumentation

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Abstract

Argumentation is a central epistemic process contributing to the generation, evaluation, and application of scientific knowledge. A key challenge for science educators and researchers is to understand how the important social and discursive ("social dialogic") dimensions of argumentation can be implemented in learning environments. This study investigates how science educators learned about such argumentation through a professional development program at a scientific research center. The 13-day program included 5-days working in research laboratories with a mentor and observing scientific argumentation in context. Theoretically, this research draws on sociocultural frameworks to investigate the social dialogic dimensions of scientific argumentation. Methodologically, it examines the reflections of a cohort of 21 secondary science teachers as they observed argumentation in scientific research settings. It examines how research experiences for teachers can promote an understanding of the social dialogic dimensions of argumentation and to help teachers take up

educational approaches that foster expansive argumentation practices. Teachers shared a heightened awareness of argumentation as a ubiquitous, embedded feature of authentic scientific activity; expanded ideas about forms, uses, and purposes of argumentation; and developed an understanding of how contexts for argumentation such as collaborative sensemaking and critique can help manage uncertainty and build knowledge. A year after their program participation, teachers recounted shifts in pedagogical practices, including desettling traditional classroom talk patterns, scaling back their epistemic authority, providing students with more agency and ownership of ideas, and recognizing the value of establishing a culture of community and collaboration. Findings highlight how professional development in research settings has the potential to broaden teachers' views of argumentation, with implications for secondary science teaching.

1 | INTRODUCTION

> I wish that students could sit in on [a professional science lab meeting]...a couple of takeaways that I got were that the presenter does not always know the answer, and that's okay...There were a lot of questions being asked and he was very not defensive at all, which I feel like kids get.... I also feel like it's important to do those open investigations to make that argumentation work. Otherwise, everyone is doing exactly the same thing and there's no discussion. (Elizabeth, small group discussion)

In the quotation above, a science teacher shares her thoughts from attending a scientific lab meeting—specifically, her insights about the presenter's acknowledgment of not having all the answers, the role of the audience in critiquing ideas, and what kinds of investigations and structures would be necessary to make "argumentation work" with students. Elizabeth's statement addresses not only her take-aways about scientific discourse but also connects her reflections to her students and classroom. Her observations suggest the power of bringing teachers into research settings with the explicit goal of observing scientists engaged in argumentation with one another.

The view of science as a set of socially negotiated practices enacted by members of a knowledge-building (i.e., "epistemic") community has deep historical roots in science education research, philosophy of science, and science studies (Latour & Woolgar, 1986; Rouse, 1996).

Recently, it has also found traction among science teachers and the science education community because of the vision put forth by the *Framework for Science Education* (National Resource Council, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013). Argumentative practices are particularly critical to scientific inquiry as they underlie scientific activity and are at the root of the social construction of scientific understanding (Berland & Reiser, 2009; Duschl & Osborne, 2002; Ford & Forman, 2006). Consequently, researchers have noted the need to represent argumentation in science education classrooms (Berland & Reiser, 2009; Driver et al., 2000; Duschl, 2008; Erduran & Jimenez-Aleixandre, 2012; Kuhn, 2010). Argumentation can provide students with important insights into how professional scientists make and defend claims and how they wrestle with the uncertainty inherent in scientific inquiry (Manz, 2018). Arguments have characteristic structures that help coordinate claims and evidence (Toulmin, 1958) but are also forged and tested in dialog with others (McNeill & Knight, 2013). The social and discursive ("social dialogic") aspects of argumentation in educational settings have been less frequently studied than argument structure (Berland & Reiser, 2009; McNeill & Knight, 2013).

A critical question is how teachers come to value the inclusion of social dialogic argumentation in their classrooms. While the NGSS standards are a driver for teachers to think about argumentation, what motivates them to shift their classroom practices to not only include argument structures but also to broadly conceptualize the practice of argumentation, decenter their own power in classroom talk, and create new opportunities for shared social sensemaking among students? Collaborative discourse and argumentation play a key role in helping scientists—as well as students—make meaning and develop common knowledge with their peers. While teacher professional development opportunities in professional science research settings have the potential to provide educators with deeper understandings about scientific practices such as argumentation, little is known about what teachers learn about practices in such contexts or how they consider the implications for their work with students. This represents a missed opportunity in teacher professional development. This study was guided by the following research questions:

- What do secondary science teachers learn about the social dialogic dimensions of argumentation and its role in scientific sensemaking through participation in professional development that includes research experiences?
- How do teachers′ observations in professional research settings influence their conceptions of the role of social dialogic dimensions of argumentation in science and in secondary science instruction?

2 | BACKGROUND

2.1 | Research experiences for teachers

One of the ways that educators can deepen their understanding of the role that argumentation plays in research settings is through participation in Research Experiences for Teachers (RETs). RETs have long been supported at wide range of scientific institutions through programs such as the National Science Foundation Research Experience for Teachers (NSF-RET). Such experiences are predicated on the assumptions that participating in such experiences will enhance teachers′ understanding of science and enable them to shift their teaching to reflect scientific practices more authentically (Feldman et al., 2009).

Many science teachers lack direct experience conducting research or using scientific practices (Schwartz et al., 2004; Southerland et al., 2016; Windschitl, 2003; Windschitl et al., 2008). Their conceptions of science are shaped largely by their own educational experiences as science students—which may include prior exposure to the "scientific method" in courses and textbooks as a linear and inflexible heuristic (Kite et al., 2021; Windschitl, 2004). Undergraduate laboratory science experiences tend to be primarily confirmatory (Windschitl, 2003) and preservice teacher programs rarely incorporate experiences which would allow teachers insight into scientific practices (Hofstein & Lunetta, 2004). Other researchers have noted the affordances that research experiences might have for helping teachers broaden their understanding of scientific practices and their importance (Capps & Crawford, 2013; González-Howard, 2019). As Kite and colleagues note, "if science teachers' academic and professional experiences do not provide ample opportunities for them to practice what scientists do, then they will be likely to teach in the same way that they were taught, which will, in turn, contribute to students' common misconceptions about scientific inquiry" (2020, p. 14).

Researchers have investigated the impact of RETs on teacher's beliefs, attitudes, and values about teaching science as inquiry or on their classroom practice (Enderle et al., 2014; Krim et al., 2019; Sadler et al., 2010). Although teachers in these programs emerge with greater understanding of both science disciplinary content and scientific activity, research indicates that bringing insights from their research experiences into their classrooms remains a struggle (Brown & Melear, 2007; Lotter et al., 2007; Lunsford et al., 2007).

2.2 | Research experiences and teacher professional development

Some RETs also include professional development experiences for science teachers that incorporate opportunities for learning pedagogical strategies and reflection alongside the research experience. Enderle et al. (2014) compared 120 teachers in two RET experiences over 5 years: one whose primary aim was conducting scientific research, and another that was also focused on pedagogy. Teachers in both groups improved in their views toward research and inquiry. However, the group that provided teachers with support from master teachers and opportunities for reflection were more successful in shifting teacher's beliefs and impacting their practice. Other researchers have also noted the importance of the pedagogical and reflective components of RET programs. This includes supporting teachers' ability to facilitate productive disciplinary discourse and talk (Engle & Conant, 2002; Michaels et al., 2008). Capps and Crawford (2013), working with 5 ninth-grade teachers found that teachers receiving explicit discussion and reflection related how to teach the topics of the workshop (geology and evolution) had greater gains in subject matter and more informed views of the nature of science than the comparison group that only conducted research. Programs that provide teachers with opportunities and structured support to reflect on connections between their science experiences and their classrooms to bring those experiences back to their work with students are also more likely to shift teaching and result in increased student engagement in scientific practices (Krim et al., 2019; Sadler et al., 2010).

Investigations into teachers' experiences are often focused on their involvement with research projects, rather than how they experience instances of practices such as argumentation among scientists. Southerland et al. (2016) found that the nature of the social interactions teachers experienced in labs strongly influenced their beliefs. They also noted that science learning requires engagement in the epistemic practices of science, particularly in the discourse

that fosters meaning-making and sensemaking. This finding has implications for both teacher professional development as well as student learning of scientific practices such as argumentation. It suggests the importance of focusing teachers on social dimensions of scientific practices such as social dialogic argumentation and providing them with opportunities to process their experience with others.

While prior studies examined a broad range of outcomes from RETs or similar programs, none of the studies reviewed examined the impacts on participants' understanding of the role of social dialogic argumentation in science. This research project aims to fill that gap by drawing teachers' attention explicitly to instances of argumentation in professional science, providing opportunities to reflect on and discuss scientific practices they observe, and involving teachers in considering the implications of their experiences as they endeavor to bring them to their classrooms.

3 | CONCEPTUAL FRAMEWORK

This work uses a sociocultural theoretical lens to frame and make sense of findings. This perspective illuminates the social and cultural dimensions of scientific activity, the research experiences of teachers, and science learning of students in the classroom. A sociocultural view acknowledges the complexity of learning, the importance of interactions and relationships with others, context and situation, and the role of mediating tools such as language (Lave & Wenger, 1991). As Lemke (2001) notes, "what matters to learning and doing science is primarily the socially learned cultural traditions of what kinds of discourses and representations are useful and how to use them (p. 298)."

Argumentation in science is "a knowledge building and validating practice in which individuals attempt to establish or validate a conclusion, explanation, conjecture, or other claim on the basis of reasons" (Sampson & Blanchard, 2012, p. 2). The inclusion of argumentation within school science provides students with broader insight into how scientific knowledge advances while giving them experience with the social processes that underlie the construction of scientific ideas (Bell & Linn, 2002; Bricker & Bell, 2008; Duschl & Osborne, 2002). This research study takes an expansive, situated, and interconnected view of argumentation, in line with the ways that the practice is actualized in professional research settings. Driver et al.'s (2000) note that argumentation can be considered "as an *individual* activity, through thinking and writing, or as a *social* activity taking place within a group" (p. 291, emphasis in the original). Scientists often make formal structural arguments individually, particularly attempting to persuade others in written journal articles or presentations. However, they also engage in fluid and socially situated arguments as they develop explanations for their findings, build new knowledge, and make sense and meaning with their peers.

Argumentation also has both structural and dialogic components, which are synergistic (Erduran & Jimenez-Aleixandre, 2007; McNeill & Pimentel, 2010). Strengthening claims through use of appropriate evidence and reasoning allows those claims to stand up more strongly to the critiques of others. Similarly, when students collaboratively engage in dialogic processes of questioning and building on ideas, they can hone and sharpen the structure of their arguments (Berland et al., 2016; González-Howard, 2019).

Table 1 maps individual and social dimensions of argument against structural and dialogic components. Much of the activity and educational research in schools has focused on structural dimensions of argumentation and how students craft arguments (Sandoval & Millwood, 2005),

TABLE 1 Argumentation foci and features

	Argumentation features	
Focus	**Structural**	**Dialogic**
Individual	Creating a formal argument or statement	Creating internal dialog or processing
	Research example: preparing a presentation to explain findings	Research example: one scientist's reflective processing to debate merits of different arguments
	School example: writing a conclusion using a claims/evidence reasoning structure	School example: one student's internal anticipation of the critique of others
Social/ Group	Working collaboratively to strengthen structure of argument	Processing ideas or findings together with others as part of larger group sensemaking
	Research example: lab works on a paper's argument flow	Research example: lab meeting to discuss and analyze latest puzzling data collectively
	School example: students interrogate one another's argument structures	School example: seminar meeting to understand results from an open-ended lab activity

which is represented in the upper left quadrant (individual/structural). This study focuses on the bottom right quadrant. Examples show how different dimensions of argumentation might manifest in a research or classroom setting. There is overlap between these categories: individuals participating in social dialogic argument still incorporate structural pieces but put them into a critical conversation alongside the ideas from others.

3.1 | Dialogic argumentation in science education

Scholars have noted the critical need to support students in the dialogic aspects of argumentation (such as critique and collaborative sensemaking) that are reflective of knowledge-building in scientific communities (see Table 1, Dialogic Column) (Bell, 2004; Berland & Reiser, 2011; Duschl & Osborne, 2002; Ford, 2012; González-Howard, 2019; González-Howard & McNeill, 2019; National Resource Council, 2012; Osborne, 2010). Berland and Hammer (2012) note how overemphasizing argument structure can result in argumentation being viewed as part of the "classroom game" (Lemke, 1990, p. 11) by students. They argue that "introducing argumentation through explicit instruction in how to argue might undermine framings that are more consistent with scientific argumentation and therefore inhibit student engagement in this practice" (p. 88). An over-reliance on argument structure pulls selected, isolated elements of the broader practice of argumentation from larger activity systems, effectively decontextualizing them (Manz, 2015). It also emphasizes the explanatory aspects of argumentation, rather than the situated nature of argument, reflecting a view of argument as "product of inquiry rather than an enmeshed component of inquiry" (Cavagnetto, 2010, p. 352).

For classroom argumentation to reflect scientific practices more accurately, teachers need to present argument broadly, not only as a structured form of reasoning with evidence, but also as an embedded, situated dimension of scientific inquiry that is often negotiated discursively through collaborative sensemaking and critique. Students need experience analyzing data and constructing claims individually but also need opportunities to connect their ideas to those of

other students, considering alternative claims and critiquing them within a social context—the bottom right quadrant in Table 1 (McNeill & Pimentel, 2010).

3.2 | Teacher professional learning and classroom social dialogic argumentation

The role of the teacher in creating environments where the students listen to, critique, and question the arguments of others is pivotal (Simon et al., 2006). Shifting science education to include a focus on practices such as argumentation requires that teachers be prepared to provide appropriate framing contexts that represent those practices (Berland & Hammer, 2012). Professional development is key to helping teachers understand the role of scientific argumentation in scientific knowledge production (McNeill & Knight, 2013; Osborne et al., 2019; Sampson & Blanchard, 2012; Sandoval et al., 2016).

Teachers need an understanding of argumentation, including what counts as an argument and how scientific arguments are evaluated, to promote the epistemic dimensions of argumentation in their classrooms. Sampson and Blanchard (2012) note that teachers may lack specific pedagogical knowledge and instructional resources necessary to incorporate social dialogic argumentation. In their study, teachers demonstrated difficulty using evidence-based argumentation to distinguish among competing explanations and relied on prior knowledge (instead of data) to evaluate the validity of arguments.

Teachers may also find integrating argumentation into their classrooms challenging because their beliefs about what argumentation is, the forms it should take, and how it connects to the nature of science itself (González-Howard, 2019; Sampson & Blanchard, 2012; Simon et al., 2006; Windschitl et al., 2008). For example, if teachers define science as primarily a set of known facts to transmit to students, or if they view argumentation as ineffective for teaching content, they are less likely to prioritize it in their classrooms (Sampson & Blanchard, 2012). Teachers may struggle generally with incorporating argumentation and other dialog-intensive practices into their classrooms because of the common tendency to want to correct student misconceptions and answer their questions directly (Lotter & Miller, 2017). They may find it difficult to reconcile their images of scientific argumentation with their perceptions of the resources and competencies that students bring to school or be uncertain about how to shift discourse and classroom power structures in necessary ways (Cazden, 1988; Henderson et al., 2018; Hudicourt-Barnes, 2003; Snell & Lefstein, 2018). Additionally, they may view argumentation negatively because of the popular association of the term with conflict or social dispute (Bricker & Bell, 2008).

Research has demonstrated the value of providing teachers with professional development focused on argumentation (Osborne et al., 2019; Sadler, 2006). McNeill and Knight (2013) described how professional development from a perspective grounded in authentic classroom practice can increase teachers' pedagogical content knowledge of structural dimensions of written argumentation (although teachers found analyzing classroom discussions for structural and dialogic characteristics challenging). Professional development can also enhance teachers' ability to facilitate quality argumentative discourse with their students. For example, Osborne et al. (2019) found that practice-based professional development can result in significant changes in elementary teachers' ability to scaffold evidence-based scientific argumentation in their classrooms. Research also indicates that teachers who have a deeper understanding of the purposes and construction of arguments can better support students in understanding the epistemic

dimensions of argumentation (McNeill et al., 2017). However, there is a lack of studies exploring what science teachers learn about social dialogic argumentation when engaged in professional development experiences within scientific research labs.

3.3 | Social dialogic argumentation and power in classrooms

Teachers traditionally position themselves as the primary speaker and questioner in classroom science talk (Cazden, 1988). Learning, however, involves participation in practices of a community, including the special ways people talk within that community (Lave & Wenger, 1991). When teachers shift some of the epistemic authority for talk onto students, for example, by incorporating social dialogic argumentation, they can disrupt the conventional ways that power in the classroom is dynamically constructed through patterns of discourse. Moreover, it is not simply giving students voice by increasing the amount of time students talk with one another that matters. Rather, students need opportunities to build knowledge actively, engage in talk that reflects the progressive discourse of science, and to express, test, and refine their own ideas (Bereiter, 1994; Berland & Hammer, 2012; Scardamalia & Bereiter, 2006).

The ways in which teachers create opportunities for talk sends a message to students not only about appropriate discourse in the classroom but also about what science is and who gets to participate in it. In this way, both knowledge and power are situated within classrooms and directly connected with one another. As Gutiérrez and colleagues point out, "power is locally constituted through the various configurations of talk and interaction in the classroom" (Gutiérrez et al., 1995, p. 446). They note that for traditional modes of classroom talk, the "teacher's epistemic stance, revealed through the monologic script, helps define what counts as valued knowledge in this classroom and thus determines whose knowledge is constructed" (p. 450). In addition to providing accounts of teachers' insights about argumentation in a research setting, this study describes how several teachers created opportunities for social dialogic argumentation in their classrooms afterwards– such accounts are also missing from science education literature.

4 | METHODS

4.1 | Setting

The Science Education Partnership (SEP) is a professional development program for secondary school science teachers embedded in Fred Hutchinson Cancer Research Center, a scientific research institute of over 3000 people. Since 1991, the program has provided over 580 teachers with direct experience in research labs, curricular support, and access to equipment and supplies. The overall program included: (a) An intensive 13-day summer session in which teachers worked closely with each other, staff, and scientist mentors to gain skills and expertise in molecular biology; (b) Time and assistance during the session to develop a curriculum project related to the program for their classrooms; (c) Access to an extensive molecular biology kit/equipment/supplies loan program; and (d) Additional meeting times throughout the school year to prepare teachers for the experience, reflect on its impacts, and bring the larger community of teachers together. The additional meetings times included a full day orientation, a follow-up reflection day at the end of the school year, a kit-sign up day, and four academic-year 1-day workshops.

4.2 | Participants

There were 21 cohort teachers (see Table 2). Additionally, four lead teachers contributed their thoughts and helped lead discussions. The cohort reflected the general demographics of science teachers in the region: teachers identified mostly as white females. Two teachers identified as Asian and one teacher as male. While 13 teachers had some prior research experience, eight teachers had none. Most teachers were high school educators and taught in public schools; three taught middle school and two taught in independent schools. There was a relatively even distribution of teaching experience in the cohort, with 11 teachers having more than 5 years of experience and 10 teachers fewer than five. Eight teachers reported that over 50% of their

TABLE 2 Participants

Teacher pseudonym	Grade level	Education: Science	Education: Teaching	Research exp.	Years teaching	School
Anna	9–12	BA-Bio	MIT	Y	2	Urban
Bethanie	9–12	BS-Bio	MAED	Y	3	Urban
Cara	7–12	BS-Bio MA-Zoology	Secondary Certification	Y	5	Suburban
David	9–12	BS-Bio/English	Secondary Certification	Y	15	Rural
Elizabeth	9–12	BA-Comms	MIT	N	0 (Pre)	Urban
Jan	9–12	BS-Zoology	MEd	Y	33	Urban Parochial
Jenn	6–8	BS-Fisheries	MEd, MIT	Y	4	Urban
Jolene	9–12	BS-Bio	MEd	N	9	Suburban
Lisa	9–12	BA-Bio MS-Fisheries	-	Y	10	Urban Private
Libby	9–12	BS-Bio Ed	BS-BioEd	Y	2.5	Suburban
Louise	9–12	BS-Bio	MIT	N	9	Suburban
Marisa	9–12	BS-Bio	MAED	Y	6	Urban
Melissa	9–12	BA-Human Bio	MIT	N	17	Suburban
Mollie	9–12	BS-Bio	MIT	Y	10	Suburban Private
Randi	9–12	BS-MolBio MS/PhD Pharm	Secondary Certification	Y	14	Suburban
Raven	9–12	BS-Zoology, MS-Genetics	MA-Science Ed	Y	10	Urban
Rhea	7–8	BA-Humanities	MIT	N	3.5	Urban
Satya	9–12	BS-Bio	MIT	N	4	Urban
Tamara	9–12	BS-Bio	MIT	Y	2	Rural
Teri	9–12	-	MAT	N	9	Rural
Victoria	9–12	BS-Bio	MEd	N	6	Urban

Note: Shading indicates teacher is referenced in article.

students were from groups historically underrepresented in STEM. Nine teachers reported that over 50% of their students received free or reduced lunch.

4.3 | Program design

The program was structured to highlight that scientific argumentation as a practice involves not only the coordination of claims with evidence through reasoning, but also social collaborative and discursive processes of critique and deliberation. The main design conjecture (Sandoval, 2004) driving the theory of action was that broadening teachers' abilities to enact productive instances of social dialogic argumentation with students could be facilitated not only by providing pedagogical strategies and support, but also by creating opportunities to notice and reflect on the central role of argumentation in science research settings.

The outcomes that the design aimed to achieve were both epistemic and pedagogical: That teachers would have a broader understanding of argumentation and its epistemic role in science and would subsequently enact opportunities for knowledge-building through social dialogic argumentation in their classrooms. The program design included four main mediating processes aimed at teachers participating in the professional development: (1) Providing a vision of what social dialogic argumentation practices look like in science research settings, fostered by evidence that teachers have gathered and processed with their peers; (2) Sharing discourse strategies such as seminars modeled in the program from the perspective of a learner and teacher; (3) Offering opportunities to create/modify lessons to include elements of productive disciplinary discourse and uncertainty; and (4) Creating time for collaboration and reflection with a community of peers and lead teachers.

The program included 5 days of teachers directly working alongside scientists in research laboratories and attending lab meetings. Teachers worked on a small, hands-on project under the guidance of their mentor scientist, which allowed them to experience some of the challenges of conducting research. Teachers also used a "micro-ethnographic" approach to observe social dialogic argumentation in their lab setting and in lab meetings. The program offered RETs in part so that they could experience the cultures and practices of the labs, but also to promote a broader understanding of social dialogic argumentation as it is used in science settings. Table S1 provides an overview of the argumentation-related elements of the program. For a complete list of argumentation-related elements in the program, see Figure S1.

The program staff prepared teachers to take an ethnographic lens to their lab experience. Prior to their week in the labs, teachers watched a video of a lab meeting with an accompanying transcript. We asked them not to try to follow all the technical details of the science shared in these meetings, but rather listen broadly to when claims were being made, what kinds of evidence were presented, how ideas were critiqued by others, and how understanding was being built. The lab meetings were the easiest places to see social dialogic argumentation in action, but we asked teachers to be open to other instances. They were asked to pay attention to argumentation and sensemaking talk and note when it happened. The list of reflective prompts for teachers to respond to in their daily journals was a key tool that scaffolded their observations in the research labs and anchored later discussions. Questions included: "What is the purpose of the argumentation or sensemaking talk? Did you hear people trying to persuade each other? Or come to a shared understanding? Did they give each other feedback or critique? Did they bring in specific kinds of evidence?" We also asked them to reflect on how research labs and science classrooms might use argumentation similarly or differently. Some teachers wrote detailed

accounts of language-in-use and captured actual turns of phrase and dialogic exchange that filled pages of their journals. From their observations, teachers selected one exemplar of argumentation to share with others. These were used in the small and large group discussions when teachers returned from their laboratories and allowed teachers to hear a variety argumentation exemplars and research experiences.

We modeled establishing class conversational agreements and developing sentence stems for probing questions that students could use with one another. We also introduced teachers to several excellent existing research-based resources available to help foster student talk in classrooms and create an environment where social dialogic argumentation can flourish (Argumentation Toolkit/Learning Design Group, 2015; Michaels et al., 2016; Windschitl et al., 2018). We engaged teachers in two seminar-style discussions: one about research results from a lab activity that they had conducted as a group, and one about a text discussing uncertainty in science. Teachers assumed student roles as we moved through these various approaches and then discussed pedagogical strategies and implications in their role as teachers afterwards. During the last week of the program, teachers had the opportunity modify an existing lesson or unit, or develop new materials suited for their specific students and circumstances. "Lead" teachers (program alumni) facilitated instruction and supported teachers in developing final projects. Specific resources were provided to help teachers try to incorporate social dialogic elements of argumentation into their classroom plans. Teachers had multiple opportunities to process and discuss their ideas throughout the program in both facilitated and informal ways.

4.4 | Data sources

The data corpus included data from teacher discussions (over 17 h of transcribed audio-recorded discussions, which were analyzed using Dedoose® analysis software); teachers' written reflections (1550 pages of writing in teachers' lab notebooks); and survey data. These data sources and the timeline of data collection are detailed in Table 3. Each data source contributed data toward addressing both research questions. I also wrote notes and analytical memos (Heath & Street, 2008) throughout the research process. A description of argumentation-related activities incorporated into the workshop, as well as surveys, are included in the Methods Supplement accompanying the online article. All 21 teachers completed the pre-survey, 20 completed the post-survey, and 19 completed the year-end survey. Direct quotes or reflections from 12 teachers are included in this article.

4.5 | Data analysis

I used a ground theory approach (using both a priori and emergent codes) to inductively coded participants' written data and audio transcripts (Glaser & Strauss, 1967). Initially, I examined the data corpus looking for relevant data related to my research questions. I focused on any data related to argumentation (particularly social dialogic aspects). I also used a process of open coding, looking for potentially relevant ideas and themes (Merriam & Tisdell, 2016). In my first pass through the data, I established 65 possible codes. Over the next year, I worked my way back through the data and re-coded it for intra-coder reliability, to find additional examples, and to look for disconfirming evidence, narrowing the focus down to 26 codes. I discussed emerging themes with teachers and other researchers and tried to establish relationships

TABLE 3   Data sources, description, and timeline

Data collection		
Data source	**Description**	**Timeline**
Journals (photocopies)	Teachers kept a physical lab notebook and journaled their reflections daily during the PD. Teachers were asked to write about their encounters with new scientific content and practices they observed or participated in. Before the small group discussions, teachers responded to a set of reflection questions in their journals before talking to the group. They also recorded lab procedures and general reflections.	Throughout the PD experience
Surveys (Likert scale and open-ended questions)	Survey questions focused on teachers' prior uses of argumentation structures in their classrooms, their insights from their immersion experiences related to their teaching practice, and classroom implementation.	Surveys were administered at the end of summer PD, and at a follow-up session at the close of the school year in May
Discussions (audio recorded and transcribed)	Facilitated small group discussions, impromptu small group discussions (e.g., during project planning), and large-group discussions/debriefs.	Facilitated small group discussions occurred four times: At the beginning of the PD, following the week in research labs, at the end of summer, and at the end of the school year. Large group discussions happened after each small group discussion and at the end of the summer program.

Abbreviation: PD, professional development.

between themes. Finally, I identified six parent codes for further analysis. The first five codes related to how teachers were making meaning about social dialogic argumentation in the research setting: the ubiquity of argumentation as part of its epistemic role, expanded uses of argumentation (beyond formal conclusion writing), social sensemaking and dialogic argumentation, productive uncertainty and class activity structures, and critique. An additional code emerged toward the end of the analysis (power) and was useful for thinking about the contextual factors related to dialogic argumentation, both in professional scientific settings as well as in schools (see Table 4). This code included data related to teachers' own experiences observing power dynamics in research labs and their relation to argumentation, as well as ones related to their attempts to shift power in their own classroom (sub-codes such as "teacher taking themselves out of the conversation (stepping back)," "elevating students as a resource for each other's learning," and "increasing equity in student talk (no one knows the 'right answer')." The theme of power explored ideas related to classroom shifts in epistemic authority and engaging students' equitable contributions to social dialogic argumentation, which are highlighted in the school-year findings.

TABLE 4 Coding scheme

Code	Description	Example
Ubiquity/epistemic role	How integral and common argumentation is to the everyday work of scientists	"In the lab, scientists are constantly talking with one another and reflecting on their practice...Most interestingly, scientists communicate with scientific/ argumentation talk all the time, seemingly unknowingly to themselves"
Expanded uses of argumentation (beyond developing formal conclusions)	Using argumentation to develop procedures or understanding data	"There was so much argumentation, and a lot of it had to do with things like... 'Do my gates look like your gates? I tried this different gating technique and I'm not sure which technique is better, look at my results, what do you think, which one should I use?'...That sort of sense-making talk can happen a lot around data."
Social sensemaking and dialogic argumentation	The role of social interactions in dialogic argumentation	"There were a lot of clarifying questions and a lot of people saying, "Maybe I'm not getting this but I'm going to throw this out here...I'm still a little bit confused about this and maybe it's some background knowledge I'm missing but it seems that something blah, blah, blah, blah. Can you help me understand?"
Productive uncertainty	Uncertainty in science and/or connections between uncertainty and argumentation	"Even the presenter is asking the listeners for more help. Socially, people are willing to admit the gap in their understanding. They offer suggestions, they suggest that the current understanding has limitations and perhaps we need to be more creative about examining things."
Critique	The purposes and uses of critique	"I was just thinking about our discussion in regard to observing how scientists talk to one another, we were talking about the role of criticism and how that plays a part in how scientists work together and talk to each other."
Power	Power dynamics in labs and classrooms and how those influence discourse	"Just that idea that the leader at the top has such a profound effect on the group dynamics. I was reflecting on that as a teacher how we all are at the front of our room leading and how the personality of the teacher just has that effect throughout."

Data from six teachers contributed to the theme of "ubiquity," and data from 12 contributed to the "expanded uses of argumentation" theme. Data for the "role of critique" theme came from 10 teachers. Data for the "social sensemaking" theme came from 13 teachers, and the "power"

theme from 12 teachers. Because many of the teachers' reflections and comments overlapped into multiple codes, I wrote memos to highlight exemplar quotes, organize and describe teachers' insights, and look for connections between them. I asked researcher colleagues to code a sample of data to ensure that my codes were aligned with theirs. I also triangulated multiple data sources (surveys, discussions, written reflections) to confirm my findings and shared my analysis with the participating teachers to member-check my interpretations (Merriam & Tisdell, 2016).

4.6 | Generalizability

This study used primarily qualitative methods because of its focus on how teachers interpreted and assigned meaning to their experiences in the program and upon return to their classrooms. It explored participants' beliefs related to scientific argumentation, especially social dialogic argumentation. This study was not designed to result in causal, probabilistic, or statistical claims about the prevalence or distribution of findings. However, this type of qualitative research has the potential for other kinds of generalizability, including analytic and inferential generalizability; findings generalize to conceptualizations that may also resonate with readers, who can connect them to other contexts (Polit & Beck, 2010; Ritchie et al., 2013; Shulman, 1997; Smith, 2017). Overall, this research provides a naturalistic inquiry into how teachers responded to opportunities to observe and learn about social dialogic argumentation through a professional development workshop and research experience (Denzin & Lincoln, 2003; Sadler, 2006; Windschitl et al., 2008).

5 | FINDINGS

This section first describes how teachers' thinking changed generally across the cohort and program. It then explores specific themes related to teachers' thinking about social dialogic argumentation in science during the summer workshop and lab experience and into the following school year. Finally, it provides selected accounts of classroom experiences.

5.1 | General program reflections

In their initial reflections, I asked teachers to record the answers to the following questions in their lab notebooks: "What do you think the NGSS mean by the practice of scientific argumentation? How do you understand the practice of scientific argumentation as described in the NGSS?" Initially, about half (11/21) teachers mentioned a social dialogic component to argumentation, but for six of those teachers this was defined in a very brief sense of focusing on argumentation as discussion (e.g., "Scientific argumentation can be defined, for me, as holding discussions about scientific topics or discoveries" or "A thorough discussion of what occurs, how it happens, and why it logically makes sense to occur"). One teacher focused explicitly on persuasion, stating that the purpose of argumentation is "to convince other people of your point of view or facts."

About half of the teachers (10/21) described the importance of using evidence to make claims and draw conclusions, with two explicitly using the language of "claims, evidence, reasoning" (C-E-R): "Scientific argumentation is similar to a C-E-R. Having some sort of claim

based on evidence and applying scientific reasoning to that." Five teachers combined the language of making evidence-based claims with the need to engage in discourse (e.g., "Scientific argumentation is engaging in discussion with peers to discuss/debate scientific concepts/results/validity. I would define it as dialog between peers to evaluate scientific data/evidence and claims.").

At the end of the summer, teachers recorded whether their definition of argumentation and its purposes had changed (one teacher had to leave early for medical reasons). The lab notebook prompt was: Look back at your definition of argumentation and description of the purpose of argumentation. How have your ideas changed/broadened, if at all? Every teacher (20/20) wrote about either a deeper understanding of argumentation in science or a desire to bring social dialogic argumentation to their students. Many teachers (9/20) talked explicitly about their understanding of social dialogic argumentation. For example, one wrote: "In my reflection earlier I had mostly considered written argumentation but a lot of argumentation in the classroom and in the "real world" of science labs involves verbal argumentation." Another noted that "When I first reflected on scientific argumentation I focused on persuasion...I now see that argumentation is also the daily discourse a scientist may do to answer a question or further a theory." Eighty percent (16/20) wrote about their ideas for classroom implementation, often related to the seminars we practiced or lab meetings they witnessed.

Teachers participated in a final survey at the end of the subsequent school year. Every teacher responding (19/19) agreed that their thinking about communication in science and argumentation as a scientific practice changed since they started the program. For example, one of the teachers noted that she "used to think of argumentation as choosing a position and providing data as to why you are correct" but now thought that "the position or idea is not the end point but it is the start of a discussion." Another teacher noted, "My idea of scientific discussion has definitely been evolving...traditionally science teachers are not trained to do a lot of discussion-type activities but I hold it at a higher value and therefore am making more time to implement it." One teacher wrote "It's not all just stating evidence and what students think it means. It's problem solving and finding ways to work together."

Teachers at the end of the school year also noted that observing how scientists talk influenced how they structured discursive opportunities for their students, affirming the value of providing focused, embedded experiences in professional scientific settings for teachers. In response to the question, "Did observing how scientists talk to one another in lab meetings and during the course of their work influence how you structured opportunities for talk in your science classroom?", the majority (15/19) answered affirmatively. One teacher was not able to attend a lab meeting, another felt she already had a depth of understanding from working in research, and one noted that she did not find the lab meeting "super transformational" but was still thinking about how students could provide "critical and relevant" feedback to their peers.

5.2 | Themes

Several broad themes encompass the shifts many teachers described in their thinking. These include an appreciation of the foundational epistemic role of social dialogic argumentation and its central connection to scientific activity. Teachers also described changes in their understanding of the varied uses and forms of argumentation. They considered how knowledge-building often happens socially through argumentation and reflected on the importance of the structure of tasks and activities in facilitating students' discourse and understanding.

5.3 | The ubiquity of social dialogic argumentation

Raven discussed how her understanding of scientific argumentation had evolved. Significantly, she had not previously thought of scientists' activities as scientific argumentation.

> *I think that I had not really thought of what scientists do as "scientific argumentation" (though I've heard about that from the NSTA and other scientific education groups).* I had always thought it was about using evidence to make a point, and that it was all part of the process of science. I had not realized how important this type of communication was (and how scientists seem to talk like this often, without always realizing they were doing it consciously). I do not think I would have noticed it without the preparation I got with having to notice it. (Raven, end of year survey, emphasis added)

Raven's comment illustrates how scientific practices can be abstracted and absorbed conceptually by practices of school. Despite her familiarity with argumentation through the National Science Teaching Association (NSTA), she had been thinking of argumentation as an "external concept"—as a discrete activity, separate from other parts of science. Her workshop experience, however, helped her understand its important role and showed her how "scientists seem to talk like this often."

Other participants also noticed how important social dialogic argumentation was to scientific activity and how common it was throughout. Bethanie had recorded dialog in the lab that she noted seemed to reflect every conversation in the lab—scientists talking with one another trying to make meaning from puzzling results:

> I just recorded a conversation that I can rehash. [One scientist] said, "What do you think about blahdiblahblah?". The second guy was like, "Oh I'm not sure, I've read so many papers on it, I'm not sure what the best way to go is" ...Then this other guy stepped in...and is like, "Show me the results that you got last time", so they are looking at her computer and discussing p values and options for next steps. They were interrupting each other, and another guy jumped in, but it was like they were excited about it. It wasn't rudely interrupting. It was building on each other's ideas as they were going...It was just lots of analogies and back-and-forth conversation. They were very open in putting out an idea even if it ended up being wrong. It was like the conversation was happening so quickly that there were lots of wrong ideas thrown out. Then they would be like, "But wait, that can't be right because of blah blah blah." *That was how every conversation in the lab went.* (Bethanie, discussion, emphasis added)

5.4 | Expanded uses of argumentation beyond developing conclusions

Several teachers observed that argumentation in lab settings can be used for purposes other than conclusion writing. They specifically noticed when argumentative talk centered on determining the most appropriate procedure, troubleshooting a procedure that wasn't working as expected, or trying to make sense of results. For example, Louise jokingly referenced a scientist whose primary role appeared to be talking to others about data analysis and techniques/

procedures rather than doing lab work. She noted that there was "so much argumentation, and a lot of it had to do with things like, 'I tried this different gating technique and I'm not sure which technique is better. Look at my results, what do you think? Which one should I use?'" Similarly, Victoria noticed the prevalence of argumentation in developing procedures and designs in the earlier stages of problem solving. She noted that much of the argumentation talk she observed was at the beginning of a problem rather than at the end:

> I wrote in my original [reflection] that scientific argumentation is often like your C-E-R. This is my claim at the end, this is my evidence that I've gotten, and this is why. A lot of what the talk I heard in my lab was they are at the beginning of the problem. They do not have a claim yet. They have ideas but it's more discussion on problem solving or like, "Oh my control produced a product—it shouldn't have. Why might that be happening? Everything worked but this tube and I can get everything to go but this one. What's going on?" (Victoria, discussion)

After her lab experience, she reflected on and expanded her ideas of what argumentation looks like in science beyond the C-E-R (Claims-Evidence-Reasoning) structural framework often used in classrooms to justify a lab conclusion. Louise and Victoria demonstrated expanded conceptions about argumentation; they noticed that scientists used argumentation in research settings in discussion and problem-solving with others throughout different phases of scientific activity.

5.5 | Social sensemaking and dialogic argumentation

Several teachers expanded their understanding of argumentation to specifically stress the social dimensions of sensemaking and knowledge-building and considered how this would impact their classrooms. Teachers noted that arguments develop through discussion, that multiple individuals contribute to the development and evaluation of scientific claims, and that social sensemaking has an important role in science. For example, Rhea wrote:

> I have refined my definition of argumentation. I would say now that it seeks to share what is known through the input of many scientists. When a presenter does not know the answer, they seek insight from peers. Using a lab meeting format leads to more authentic argumentation discussions and a better idea of what is meant by 'peer reviewed'.

Mollie connected the ideas of the central role of argumentative talk in scientific activity with the idea that claims can be developed by multiple people. In her lab notebook, she talked about her shifts away from ideas of argumentation as persuasion toward a recognition of the social "daily discourse" that many individuals contribute to. Bridging to the classroom, she noted the emphasis school places on individual work—and that having students work together to build claims would be a worthwhile practice to transfer to the classroom community:

> [What] has been drilled into me in my school is that we want to have students... write their own words and not necessarily plagiarize each other...but when you are in a lab and you are *watching a claim be filled in with evidence and reasoning by six*

other people in a room...it does not have to be a singular person and that there's a lot of value to having that student-to-student discourse and...I should be encouraging that. (Mollie, end of summer discussion, emphasis added)

After Melissa had observed a lab meeting, she reflected on her changed perception of the word "argument" in science:

I am thinking now, after seeing the lab meeting in action...that the term "argumentation" in science is not at all related to the generic or legal meaning of the word "argument" where "to win" the argument is the goal. I am thinking of it now as a method to surface potentially relevant info...to advance the research...I need to improve in this to do a more effective job planting ideas for students to think about. This communication step is where the deepest collaborative learning and potential for pushing knowledge forward might occur. Even if a finding (or discovery) is made by an individual, its importance is better understood when shared with others for their response, input, insights. "Sensemaking" is more accurate when constructed with input from others. I need to build ways in the classroom for students to have more peer communication. WORK ON THIS! (Melissa, lab notebook)

The purpose of argument in scientific activity, she noted, is not to "win" an argument so much as to advance the research. She expressed a desire to build in more opportunities for students' collaborative thinking and discussion to reflect the communication involved in "pushing knowledge forward." Melissa recognized the value of communication and the social dialogic aspects of argumentation for learning and for scientific sensemaking.

5.6 | Conditions that foster social dialogic argumentation (productive uncertainty and class activity structures)

Significantly, several teachers recognized that certain kinds of activities provide the kinds of ambiguity necessary to foster productive opportunities for argumentation. Rhea noted in her lab notebook that students "need open investigation for argumentation to work". If students are pursuing a known-answer question using a predetermined strategy, opportunities for collaborative discussion and sensemaking are thwarted. A classroom investigation with some ambiguity in terms of how students craft a procedure or in terms of expected results yields a more fruitful and productive opportunity for discussion and argumentation. In the quote that opened this paper, Elizabeth shared a similar thought with other teachers when she debriefed her experience: "I also feel like it's important to do those open investigations to make that argumentation work. Otherwise, everyone is doing exactly the same thing and there's no discussion."

Some teachers shared their recognition that their current practices did not support opportunities for social dialogic argumentation. Randi noted that "I...guide them all to do it the same way so that we all kind of get the same results and almost as though the results are the most important. What I really need to do is step back and make my labs a lot more inquiry based and let it be messier because they need more responsibility." Louise had a similar sentiment about the existing curriculum at her school: "I feel like the hardest thing right now is that our curriculum at our school is what we've always been doing, so a lot of the labs we do are a means to an end. There's a right answer at the end...." Victoria shared her desire to break away from

known-answer experiments, provide more opportunities for student agency, and incorporate seminar-style discussion modeled in the workshop:

> I want to structure it like [the example seminar]...Maybe forcing them to use scaffolds in the beginning and letting them flounder and letting it be silent and letting kids take risks and really emphasizing that science only exists to figure out things that we do not know. There are all these people with PhDs and all this education and they are literally working on stuff every day where they are just like, 'I have no idea what's happening'. (Victoria, summer small group discussion)

At the end of the workshop, Melissa reflected on her initial definition of argumentation in her notebook. She pointed out the importance of using an activity structure with either inherent uncertainty or variable results to foster discussion (Engle & Conant, 2002; Manz, 2018): "Argument doesn't have to center on a controversy—a lab experience can work too! It generates evidence that is worthy of discussion but only (best?) if the outcome is not known, or has variable results."

5.7 | The role of feedback and critique in argumentation

Another theme among teacher responses related to the impact of observing the lab meeting and the activities in the research lab was the idea of supporting students in questioning and critiquing one another. Raven noted:

> As far as argumentation I found that I've come to a better appreciation of how it works in science. What seems like a hostile exchange (or what may be perceived so in another context, or people with other perspectives) is just a way to improve work and come forward on science. (Raven, end of year survey)

After seeing the importance of constructive questioning and rebuttal in her lab placement, Tamara aspired to have students become comfortable with critique or alternate interpretations. She noted the importance of going beyond asking students to develop individual argument structures toward having them address "other students' ideas and thoughts" and to use evidence-based discussion to question one another's ideas.

> When watching scientists' discourse, I noticed that they constructively question and rebut others' ideas in order to come to better conclusions and ideas. Rather than having students express their thoughts and supporting them with evidence, they need to work deeper and address other students' ideas and thoughts and either support them with evidence or use evidence to question what they are thinking. (Tamara, end of year Reflection Day survey)

Rhea noted how some of the ways in which feedback was provided in lab meetings would make good "sentence starters" for critique and social dialogic argumentation in her classroom. After observing a lab meeting, she noted:

> I got so many great sentence starters that were authentic and real...I'm just going to read off a couple because these are really great for using with students: 'And how

readily could you find different (blank) without crosslinking?... My thinking, which could be limited, is that this' ...There were a lot of clarifying questions and a lot of people saying, 'Maybe I'm not getting this but I'm going to throw this out here'. That was really cool. (Rhea, small group discussion)

5.8 | School-year experiences: Shifting power in the classroom

Teachers reconvened in May of the following year to reflect on their school year experiences and the impacts of their summer workshop. Below, I provide several examples of teachers' descriptions of classroom enactments, and how they brought ideas from their lab experiences and the professional development to their teaching.

At the end-of-year Reflection Day discussion, Bethanie shared an example of how she had altered instructional and discourse structures in their classroom to provide more epistemic authority and control to students. When Bethanie was in the research lab, she had written in her lab notebook about wanting to develop a culture that reflected the social dialogic dimensions of argumentation that she had observed. She noted how open scientists were to suggesting ideas, even if those ideas ended up being wrong. She wondered, "How did that culture develop...How can I get my students to talk to each other like this?" Bethanie's experience during the school year demonstrated her willingness to try some new talk strategies that allowed greater student participation. For example, Bethanie did a heart dissection with students, but instead of telling them how to dissect the heart and what the parts where, she asked them to hypothesize how blood flows. Students made claims based on data such as the measurements they made of the thickness of the internal structures. She followed up with a lab meeting seminar discussion, which we had modeled and deconstructed during the summer professional development session.

> Bethanie: I ended up not managing the discussion and just letting them talk about their reflection questions that I left on the board...I'm just gonna sit here and I'm gonna not do anything and see what happens.
> Jeanne [Author]: Was it hard to stay out of it?
> Bethanie: Yes, but it was so much better because when I would let them sit in silence, some kid would just ask some brilliant question after like 30 seconds of silence because they had time to think about it...So now that's my strategy and it's way better. (Bethanie, Reflection Day discussion)

Bethanie expressed excitement and surprise about her students' capabilities that were revealed when she granted them more authority for collective sensemaking and when she created space for them to bring their "brilliant" questions and ideas forward.

Randi and David also shared experiences from the school year that illustrated how they moved away from serving as the primary intellectual authority in their classrooms by stepping back from providing the "right answer" and allowing students to engage with other students' ideas. Randi wrote the following in response to a prompt asking teachers to provide an example of how their thinking about communication in science and argumentation as a practice changed since they started the workshop:

> I have found that giving students more time to discuss/argue with each other in class is strengthening their ability to communicate their ideas. I have personally

found this very challenging because my instinct is to correct misunderstandings as soon as I hear them. Instead, I have pushed myself to let the misconceptions play out between students as they debate and argue their points regarding a specific lab or lesson. I have observed students become much more persuasive when I avoid inserting myself in the dialog...in general it has increased the quality of dialog and communication in my classroom...(Randi, end of year survey)

David remarked that focusing on argumentation in the summer workshop helped him see how important that practice was for his students. Once back in the classroom, he instituted a routine for his biotech students to present lab results at least quarterly.

Students are realizing that they can listen to other students' ideas and not be threatened by alternative interpretations. This experience on argumentation was very helpful in getting me to see how important argumentation is for my students. Prior to SEP, I was the main input students had in developing their thinking in science. Now it is all my students--at least in my biotech class. (David, end of year survey)

By providing students with the opportunity to build their understanding through challenging each other's ideas, David made visible both the importance of social dialogic argumentation in building scientific knowledge and the idea that the teacher is not the only "input in developing their thinking."

Melissa and Anna created a project that reconceptualized a DNA extraction lab. In their new version, students would decide on their own protocol, provide evidence for their reasoning about the best procedure, and then discuss the results collaboratively with the class in a "lab meeting" seminar to determine a class redesign of the optimal method for all to try in a second attempt. During the school year, Melissa successfully piloted her lesson with her classes. When teachers came back to reconvene at the end of the school year for Reflection Day, Melissa talked about her experiences and considered how she had shifted her classroom practices to allow social dialogic argumentation about results:

Due to my increased awareness of promoting student communication as a scientific practice I have been more conscientious about building opportunities for student discussion into lessons. My SEP project is the best example....[My] students prepared for and conducted their own mock "lab meeting." I provided guidelines but students ran their own meeting. (Melissa, end-of-year survey)

Melissa noted that students were not only engaged, but that a lab without "one right answer" created "equal footing" and allowed more students to feel capable of contribution:

Tremendous student engagement on an experiment of their own design for which "an answer" was not known...Students were more on equal footing than in other lab activities. (Melissa, end-of-year survey)

The novel lesson design ended up being used by the program in future years to demonstrate how a small change in a common lab can open opportunities for student agency and social dialogic argumentation. It was also published in a practitioner-focused science education journal (Chowning et al., 2019).

These examples highlight how several teachers made meaning of the experiences in research labs (and in the workshop) that had a bearing on social dialogic argumentation in their classrooms. These teachers commented on the ways they subsequently shifted epistemic authority in their classrooms as they themselves stepped back while positioning students as knowledgeable and capable. Bethanie created space for social dialogic argumentation within a seminar discussion and saw students rise to the occasion in ways that surprised her. Randi and David restrained their power as a dominant voice and resisted the urge to quickly correct misconceptions and answers, allowing students to engage with one another's ideas. Melissa facilitated student social dialogic argumentation by creating structures and activities with an appropriate level of productive uncertainty (Manz, 2015). She recounted how her approach supported student agency, engagement, and fostered more equitable student participation. Several teachers in the program were excited about the implications of their observations for classroom practice; however, many also directly acknowledged the barriers they faced in their discussions. These included fears of managing open-ended discussions, the possible waste of materials with greater student choices, an inability to believe that students are capable of more, the belief that a certain amount of content is necessary before students can design experiments and engage in meaningful argumentation, and the pressures of covering content in limited time. Some teachers also referenced a kind of curricular inertia, where the "curriculum at our school is what we've always been doing". Another challenge that teachers noted was creating a context that would allow students to talk to one another despite the social barriers that might exist among them or despite their fears of vulnerability.

6 | DISCUSSION

The focus of this study was to examine how science teachers learned about social dialogic argumentation through participation in professional development that included research experiences, and to discern how teachers' observations in research settings influenced their conceptions of the role of social dialogic argumentation in professional science contexts and within science classrooms.

6.1 | Motivation to change practices

The ability to witness the central role of social dialogic argumentation in research labs was a powerful motivator for teachers, particularly when combined with resources, practice seminars, and pedagogical scaffolds to support classroom enactment. In addition, the opportunity for reflection and processing with others provided many different "windows" into how argumentation looks in research settings. Central to the design of the professional development was a micro-ethnographic approach that focused teachers on observing argumentation structures "in the wild" and discussing their observations with others. *Although our program had hosted science teachers in labs for nearly 30 years, it was not until we specifically focused their attention on social dialogic argumentation that teachers noticed it as something significant.* Several teachers commented that having focused questions helped them to pay attention to the conversations that the scientists were having in lab meetings as well as while conducting their research. Manz (2015) argues that making activity structures of science visible to teachers could help foster expansive views of argumentation. The results of this study suggest how such an experience could help educators develop more epistemically authentic visions of practice while reconceptualizing discourse and activity structures in their classrooms.

Teachers such as Bethanie and Melissa wondered how they could imbue their classrooms with the kind of argumentation discourse structures and community that they observed in the professional settings. This resulted in a motivation to make the discourse practices in their classroom align with the knowledge-building and sensemaking they saw happening in the lab. Within classrooms, changes that these teachers made in talk structures and language-in-use were connected to how they positioned themselves, their students, the discipline of science, and the broader Discourses (characteristic ways of "saying, doing, and being") of schooling (Gee, 2014, p. 47).

6.2 | Desettling traditional science education

Traditionally, science education has consolidated power in the teacher's authority as well as in taken-for-granted routines and the patterns of language and discourse that teachers and students engage in. Upon returning to the classroom, some teachers made moves not only to decenter themselves as the sole authority, but to "desettle," or disrupt, traditional elements of their science instruction in specific ways (Bang et al., 2012; Rosebery et al., 1992). These included: (a) shifting discourse structures to expand who has speaking rights and who can challenge the ideas of others; (b) scaling back their epistemic authority to promote student ownership of ideas; (c) fostering an intellectual community of learners; and (d) shifting activity structures to promote equitable participation and de-emphasize the uniform mastery of each individual student. The pedagogical moves teachers made repositioned students as capable, with ideas worthy of exploring and discussing.

6.3 | Caveats and limitations

This study focused on the experiences of teachers as they participated in a three-week summer workshop with a research exposure and follow-up at the end of the subsequent school year. This work did not extend to direct observations of classrooms but examined teachers' stories, impressions, and interpretations as they made meaning of their experiences. Teachers were in labs for limited amounts of time, and some were able to observe more argumentation than others. The program tried to offset this challenge by creating structured opportunities for teachers to share their experiences with one another, but the amount of argumentation teachers witnessed was likely to have impacted their thinking. Additionally, the cohort examined was unusual in that only one male teacher participated; although data from his contributions aligned with others, it is possible that a more gender-balanced cohort would have yielded different results. Similarly, most members of the cohort identified as white; the findings may also have been different had a more ethnically and racially diverse group of teachers participated.

The focus on scientific approaches that are the norm in many research institutions is not intended to disparage the value of other epistemological positions such as indigenous ones. Indigenous epistemologies and scientific practices rooted in other contexts have much wisdom to offer. Similarly, this work does not mean to imply that science educators should try to mold all students to be identical to professional scientific researchers. Science lab environments are clearly quite different from classroom ones and not inherently more important or valuable. There are discourse practices and power dynamics that sometimes occur in scientific settings that teachers and students would not want to emulate.

7 | CONCLUSION

Teachers play a central role in creating classroom environments that provide opportunities not only for students to engage in the structural dimensions of argumentation, but also the social dialogic ones (González-Howard & McNeill, 2019; Sampson & Blanchard, 2012). Students' ability to engage in scientific practices requires shifts in common and deeply ingrained instructional approaches—which in turn rely on teachers' awareness of, and commitments to, incorporating those practices. For the teachers highlighted in this article, incorporating social dialogic dimensions of argumentation represented a major shift in how discourse appeared in their classrooms—not only away from teacher-driven and teacher-centered talk patterns and toward meaningful student–student talk, but also toward opportunities that allowed students to put forth ideas and arguments to be interrogated and critiqued by others.

The research described in this paper suggests that brief (but purposeful and targeted) professional development embedded in research settings may be an effective strategy for broadening science teachers' understanding of the social dialogic dimensions of argumentation and could help motivate them to make classroom shifts. Shorter experiences are not only more likely to appeal to a greater number of teachers, but they could also serve to increase teachers' confidence in their abilities (Sadler et al., 2010) and interest teachers in future research opportunities.

Secondary teachers generally do not aim to fully reproduce scientific research in their classrooms (unless they are teaching an experimental research course). However, students can learn, in authentic ways, the "progressive discourse" of professional science, with its commitments to critique, open-mindedness, empirical testability, and knowledge-building (Bereiter, 1994). Bereiter argues that "typical hands-on experience has very little impact on students' understanding...what has been missing...is the discourse into which experimental findings need to be brought and critically analyzed if they are to contribute to progressive understanding" (p. 8). Even at introductory levels, students can learn how to engage in authentic ways with collaborative and critical argumentative science talk. Ultimately, elevating the role of the social dialogic elements of argumentation in science classrooms has the potential to create environments that value student voice. Because activities that generate productive opportunities for meaningful discourse are more open-ended, they also have the potential to elevate student agency if students are given more control over design or interpretation.

Science is still often presented as a *fait accompli*, appearing in schools in a way that does not reflect the processes in which scientific practices are deeply embedded. At the heart of scientific endeavors lie complex practices such as social dialogic argumentation, which need to be represented in learning environments to provide young people with a more epistemically authentic and broadly accessible image of science. Providing students with an expansive view of science may have impacts beyond simply increasing their scientific literacy: it may allow broader access to the social, cultural, and material aspects of science as well as a deeper and more meaningful engagement with its practices.

their support and comments on earlier drafts. I am particularly grateful to Philip Bell for his insights and guidance. Special thanks to Tim Potter for his steadfast encouragement and support.

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REFERENCES

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. *Human Development*, *55*, 302–318. https://doi.org/10.1159/000345322

Bell, P. (2004). Promoting students' argument construction and collaborative debate in the science classroom. In M. C. Linn, E. A. Davis, & P. Bell (Eds.), *Internet environments for science education* (pp. 115–143). Lawrence Erlbaum Associates.

Bell, P., & Linn, M. C. (2002). Beliefs about science: How does science instruction contribute? In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 321–346). Lawrence Erlbaum Associates.

Bereiter, C. (1994). Implications of postmodernism for science, or, science as progressive discourse. *Educational Psychologist*, *29*(1), 3–12. https://doi.org/10.1207/s15326985ep2901_1

Berland, L., & Hammer, D. (2012). Students' framings and their participation in scientific argumentation. In M. S. Khine (Ed.), *Perspectives on scientific argumentation: Theory, practice and research* (pp. 73–93). Springer.

Berland, L. K., & Reiser, B. (2009). Making sense of argumentation and explanation. *Science Education*, *93*, 26–55. https://doi.org/10.1002/sce.20286

Berland, L. K., & Reiser, B. J. (2011). Classroom communities' adaptations of the practice of scientific argumentation. *Science Education*, *95*(2), 191–216. https://doi.org/10.1002/sce.20420

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082–1112. https://doi.org/10.1002/tea.21257

Bricker, L. A., & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education*, *92*(3), 473–498. https://doi.org/10.1002/sce.20278

Brown, S., & Melear, C. (2007). Preservice teachers' research experiences in scientists' laboratories. *Journal of Science Teacher Education*, *18*(4), 573–597. https://doi.org/10.1007/s10972-007-9044-9

Capps, D. K., & Crawford, B. A. (2013). Inquiry-based instruction and teaching about nature of science: Are they happening? *Journal of Science Teacher Education*, *24*(3), 497–526. https://doi.org/10.1007/s10972-012-9314-z

Cavagnetto, A. R. (2010). Argument to foster scientific literacy: A review of argument interventions in K–12 science contexts. *Review of Educational Research*, *80*(3), 336–371. https://doi.org/10.3102/0034654310376953

Cazden, C. B. (1988). *Classroom discourse*. Heinemann.

Chowning, J. T., Wu, R., Brinkema, C., Crocker, W. D., Bass, K., & Lazerte, D. (2019). A new twist on DNA extraction: Collaborative argumentation and student protocol design. *The Science Teacher*, *86*(6), 20–27.

Denzin, N. K., & Lincoln, Y. S. (Eds.). (2003). *Strategies of qualitative inquiry* (2nd ed.). Sage.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312.

Duschl, R. A. (2008). Quality argumentation and epistemic criteria. In S. Erduran & M. P. Jiménez Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research*. Springer.

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*, 39–72.

Enderle, P., Dentzau, M., Roseler, K., Southerland, S., Granger, E., Hughes, R., Golden, B., & Saka, Y. (2014). Examining the influence of RETs on science teacher beliefs and practice. *Science Education*, *98*(6), 1077–1108. https://doi.org/10.1002/sce.21127

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.

Erduran, S., & Jimenez-Aleixandre, J. M. (2012). Research on argumentation in science education in Europe. In D. Jorde & J. Dillon (Eds.), *Science education research and practice in Europe: Retrospective and prospective*. Sense Publishers. https://doi.org/10.1007/978-94-6091-900-8_11

Erduran, S., & Jimenez-Aleixandre, M. P. (2007). Argumentation in science education perspectives from classroom-based research. In *Science & Technology Education Library* (Vol. 35). Springer.

Feldman, A., Divoll, K., & Rogan-Klyve, A. (2009). Research education of new scientists: Implications for science teacher education. *Journal of Research in Science Teaching*, *46*(4), 442–459. https://doi.org/10.1002/tea.20285

Ford, M. J. (2012). A dialogic account of sense-making in scientific argumentation and reasoning. *Cognition and Instruction*, *30*(3), 207–245. https://doi.org/10.1080/07370008.2012.689383

Ford, M. J., & Forman, E. A. (2006). Redefining disciplinary learning in classroom contexts. In J. Green & A. Luke (Eds.), *Review of research in education* (Vol. 30, pp. 1–32). American Educational Research Association.

Gee, J. P. (2014). *An introduction to discourse analysis* (4th ed.). Routledge.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory*. Aldine.

González-Howard, M. (2019). Exploring the utility of social network analysis for visualizing interactions during argumentation discussions. *Science Education*, *103*(3), 503–528. https://doi.org/10.1002/sce.21505

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. https://doi.org/10.1002/tea.21530

Gutiérrez, K., Rymes, B., & Larson, J. (1995). Script, counterscript, and underlife in the classroom: James Brown versus Brown v. *Board of Education. Harvard Educational Review*, *65*(3), 445–471.

Heath, S., & Street, B. V. (2008). *On ethnography: Approaches to language and literacy*. Teachers College Press.

Henderson, J. B., McNeill, K. L., González-Howard, M., Close, K., & Evans, M. (2018). Key challenges and future directions for educational research on scientific argumentation. *Journal of Research in Science Teaching*, *55*(1), 5–18. https://doi.org/10.1002/tea.21412

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundation for the 21st century. *Science Education*, *88*, 28–54. https://doi.org/10.1002/sce.10106

Hudicourt-Barnes, J. (2003). The use of argumentation in Haitian creole science classrooms. *Harvard Educational Review*, *73*(1), 73–93. https://doi.org/10.17763/haer.73.1.hnq801u57400l877

Kite, V., Park, S., McCance, K., & Seung, E. (2021). Secondary science teachers' understandings of the epistemic nature of science practices. *Journal of Science Teacher Education*, *32*(3), 243–264. https://doi.org/10.1080/1046560X.2020.1808757

Krim, J. S., Coté, L. E., Schwartz, R. S., Stone, E. M., Cleeves, J. J., Barry, K. J., Burgess, W., Buxner, S. R., Gerton, J. M., Horvath, L., Keller, J. M., Lee, S. C., Locke, S. M., & Rebar, B. M. (2019). Models and impacts of science research experiences: A review of the literature of CUREs, UREs, and TREs. *CBE—Life Sciences Education*, *18*(4), ar65. https://doi.org/10.1187/cbe.19-03-0069

Kuhn, D. (2010). Teaching and learning science as argument. *Science Education*, *94*(5), 810–824. https://doi.org/10.1002/sce.20395

Latour, B., & Woolgar, S. (1986). *Laboratory life: The construction of scientific facts*. Princeton University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Learning Design Group, Lawrence Hall of Science, & Boston College. (2015). The Argumentation Toolkit - Home. Retrieved March 13, 2019, from http://www.argumentationtoolkit.org/

Lemke, J. (1990). *Talking science. Language, learning and values*. Ablex.

Lemke, J. L. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of Research in Science Teaching*, *38*(3), 296–316.

Lotter, C., Harwood, W. S., & Bonner, J. J. (2007). The influence of core teaching conceptions on teachers' use of inquiry teaching practices. *Journal of Research in Science Teaching*, *44*(9), 1318–1347. https://doi.org/10.1002/tea.20191

Lotter, C. R., & Miller, C. (2017). Improving inquiry teaching through reflection on practice. *Research in Science Education*, *47*(4), 913–942. https://doi.org/10.1007/s11165-016-9533-y

Lunsford, E., Melear, C. T., Roth, W.-M., Perkins, M., & Hickok, L. G. (2007). Proliferation of inscriptions and transformations among preservice science teachers engaged in authentic science. *Journal of Research in Science Teaching*, *44*(4), 538–564. https://doi.org/10.1002/tea.20160

Manz, E. (2015). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research*, *85*(4), 553–590. https://doi.org/10.3102/0034654314558490

Manz, E. (2018). Designing for and analyzing productive uncertainty in science investigations. In J. Kay & R. Luckin (Eds.), *Rethinking learning in the digital age: Making the learning sciences count*. 13th International Conference of the Learning Sciences, (Vol. 1, pp. 288–295).

McNeill, K. L., González-Howard, M., Katsh-Singer, R., & Loper, S. (2017). Moving beyond pseudoargumentation: Teachers' enactments of an educative science curriculum focused on argumentation. *Science Education*, *101*(3), 426–457. https://doi.org/10.1002/sce.21274

McNeill, K. L., & Knight, A. M. (2013). Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on K–12 teachers. *Science Education*, *97*(6), 936–972. https://doi.org/10.1002/sce.21081

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education*, *94*(2), 203–229. https://doi.org/10.1002/sce.20364

Merriam, S., & Tisdell, E. (2016). *Qualitative research: A guide to design and implementation (fourth)*. Jossey-Bass.

Michaels, S., O'Connor, C., & Resnick, L. B. (2008). Deliberative discourse idealized and realized: Accountable talk in the classroom and in civic life. *Studies in Philosophy and Education*, *27*(4), 283–297. https://doi.org/10.1007/s11217-007-9071-1

Michaels, S., O'Connor, M. C., Hall, M. W., & Resnick, L. B. (2016). *The accountable talk® sourcebook: For classroom conversations that work*. Institute for Learning, University of Pittsburgh. https://ifl.pitt.edu/how-we-work/sourcebook.cshtml

National Resource Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and Core ideas*. National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Achieve, Inc.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science*, *328*(5977), 463–466. https://doi.org/10.1126/science.1183944

Osborne, J. F., Borko, H., Fishman, E., Gomez Zaccarelli, F., Berson, E., Busch, K. C., Reigh, E., & Tseng, A. (2019). Impacts of a practice-based professional development program on elementary teachers' facilitation of and student engagement with scientific argumentation. *American Educational Research Journal*, *56*(4), 1067–1112. https://doi.org/10.3102/0002831218812059

Polit, D. F., & Beck, C. T. (2010). Generalization in quantitative and qualitative research: Myths and strategies. *International Journal of Nursing Studies*, *47*(11), 1451–1458. https://doi.org/10.1016/j.ijnurstu.2010.06.004

Ritchie, J., Lewis, J., Nicholls, C. M., & Ormston, R. (2013). *Qualitative research practice: A guide for social science students and researchers*. Sage.

Rosebery, A. S., Warren, B., & Conant, F. R. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *Journal of the Learning Sciences*, *2*(1), 61–94. https://doi.org/10.1207/s15327809jls0201_2

Rouse, J. (1996). *Engaging science: How to understand its practices philosophically—University of Washington*. Cornell University Press.

Sadler, T. D. (2006). Promoting discourse and argumentation in science teacher education. *Journal of Science Teacher Education*, *17*(4), 323–346. https://doi.org/10.1007/s10972-006-9025-4

Sadler, T. D., Burgin, S., McKinney, L., & Ponjuan, L. (2010). Learning science through research apprenticeships: A critical review of the literature. *Journal of Research in Science Teaching*, *47*(3), 235–256. https://doi.org/10.1002/tea.20326

Sampson, V., & Blanchard, M. R. (2012). Science teachers and scientific argumentation: Trends in views and practice. *Journal of Research in Science Teaching*, *49*(9), 1122–1148. https://doi.org/10.1002/tea.21037

Sandoval, W. A., Kawasaki, J., Cournoyer, N., & Rodriguez, L. (2016). Secondary teachers' emergent understanding of teaching science practices. In C. K. Looi, J. L. Polman, U. Cress, & P. Reimann (Eds.), *Proceedings of transforming learning, empowering learners: The international conference of the learning sciences (ICLS)* (pp. 737–743). International Society of the Learning Sciences.

Sandoval, W. A. (2004). Developing learning theory by refining conjectures embodied in educational designs. *Educational Psychologist*, *39*(4), 213–223. https://doi.org/10.1207/s15326985ep3904_3

Sandoval, W. A., & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction*, *23*, 23–55. https://doi.org/10.1207/s1532690xci2301_2

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 97–118). Cambridge University Press.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, *88*(4), 610–645. https://doi.org/10.1002/sce.10128

Shulman, L. S. (1997). Disciplines of inquiry in education: A new overview. In R. M. Jaeger (Ed.), *Complementary methods for research in education* (2nd ed., pp. 3–30). American Educational Research Association.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education*, *28*(2–3), 235–260. https://doi.org/10.1080/09500690500336957

Smith, B. (2017). Generalizability in qualitative research: Misunderstandings, opportunities and recommendations for the sport and exercise sciences. *Qualitative Research in Sport, Exercise and Health*, *10*(1), 137–149. https://doi.org/10.1080/2159676X.2017.1393221

Snell, J., & Lefstein, A. (2018). "Low Ability," Participation, and identity in dialogic pedagogy. *American Educational Research Journal*, *55*(1), 40–78. https://doi.org/10.3102/0002831217730010

Southerland, S. A., Granger, E. M., Hughes, R., Enderle, P., Ke, F., Roseler, K., Saka, Y., & Tekkumru-Kisa, M. (2016). Essential aspects of science teacher professional development: Making research participation instructionally effective. *AERA Open*, *2*(4), 2332858416674200. https://doi.org/10.1177/2332858416674200

Toulmin, S. (1958). *The uses of argument*. Cambridge University Press.

Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, *87*(1), 112–143. https://doi.org/10.1002/sce.10044

Windschitl, M. (2004). Folk theories of "inquiry": How preservice teachers reproduce the discourse and practices of an atheoretical scientific method. *Journal of Research in Science Teaching*, *41*(5), 481–512. https://doi.org/10.1002/tea.20010

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*(5), 941–967. https://doi.org/10.1002/sce.20259

Windschitl, M., Thompson, J. J., & Braaten, M. L. (2018). *Ambitious science teaching*. Harvard Education Press.

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