Science
Education

Moving Beyond Pseudoargumentation: Teachers' Enactments of an Educative Science Curriculum Focused on Argumentation

KATHERINE L. McNEILL,[1] MARÍA GONZÁLEZ-HOWARD,[1]
REBECCA KATSH-SINGER,[1] SUZANNA LOPER[2]
[1]*Lynch School of Education, Boston College, Chestnut Hill, MA 02467, USA;* [2]*Lawrence Hall of Science, University of California, Berkeley, CA 94720, USA*

Received 11 March 2016; accepted 23 January 2017
DOI 10.1002/sce.21274
Published online 29 March 2017 in Wiley Online Library (wileyonlinelibrary.com).

ABSTRACT: Argumentation, a key epistemic practice in science, engages students in socially constructing knowledge claims using evidence. However, teachers need support in integrating argumentation into classroom instruction. We examined teachers' enactments of an educative science curriculum and their curricular decision making for argumentation. Ten middle school teachers enacted lessons that focused on both the structure of an argument and argumentation as a dialogic process. For each teacher, we analyzed videotapes of two lessons and follow-up interviews. Across the teachers, we observed a wide range in teachers' enactments. In some instances, teachers' instructional practices aligned with the underlying epistemic goals, while in other cases the structural aspects were oversimplified and discourse norms followed more traditional teacher-led patterns. To support classroom instruction to move beyond pseudoargumentation, we found three main influences on teachers' curricular decision making in classes with higher quality argumentation: (1) teachers' understanding of argumentation as an epistemic practice (rather than surface level features), (2) teachers as critically reflective curriculum users, and (3) teachers problematizing their prior teaching experiences. As a field, we need to think critically about how to design teacher education experiences to discourage the relabeling of teaching with reform-oriented terms, such as argumentation, and instead support instructional transformation. *Sci Ed* **101:**426–457, 2017

Correspondence to: Katherine L. McNeill; e-mail; kmcneill@bc.edu
Supporting Information is available in the online issue at wileyonlinelibrary.com.

INTRODUCTION

Recent reforms in education push for a new vision of proficiency that moves beyond the memorization of facts and rote skills to engaging students in disciplinary practices, such as argumentation (Hakuta & Santos, 2013). In argumentation, scientists engage in collaboration and critique as they develop the best explanation for a natural phenomenon through the use of evidence (National Research Council [NRC], 2012). This core epistemic practice plays an essential role in scientific discourse (Duschl, 2008). Students need to engage in argumentation to be enculturated into science and gain expertise in scientific ways of thinking (Driver, Newton, & Osborne, 2000). Although an important learning goal for k-12 classrooms, argumentation has not traditionally been prevalent in science instruction (Osborne, 2010). An emphasis on argumentation requires a classroom culture and discourse environment different from what currently prevails in schools (Duschl, 2008). Developing a classroom community that prioritizes argumentation often requires new classroom goals, such as a shift to dialogic interactions in which students collaboratively make sense of phenomena and convince each other of ideas (Berland, 2011).

The teacher's role is critical for developing classroom instruction that focuses on argumentation (Evagorou & Dillon, 2011). However, teachers can experience difficulty in constructing arguments and in understanding the function of argumentation in the science classroom (Sampson & Blanchard, 2012). One avenue to improve teachers' understanding of this science practice is through the development of educative curriculum materials designed to support teacher learning (Davis & Krajcik, 2005). Yet, creating these resources is challenging, and numerous factors cause teachers to enact curricula in different ways (Brown, 2009). To better support teachers in integrating scientific argumentation into their classroom practice, we need to understand more about teachers' decision making around curriculum implementation. Consequently, in our research, we investigated the following questions: (1) What variation exists in teachers' instruction for argumentation when enacting lessons focused on this science practice? (2) What factors do teachers discuss in relation to their decision making when enacting the argumentation lessons?

THEORETICAL FRAMEWORK

Argumentation in Science

Argumentation is a complex epistemic practice that supports students in constructing new scientific knowledge as well as revising their existing ideas, as they make sense of data and engage in dialogue with their peers (Roychoudhury & Rice, 2010). Engaging students in building on and critiquing the ideas of their peers using evidence can support significant academic achievement because it encourages explanation and self-correction of ideas (Michaels, O'Connor, & Resnick, 2008). As students engage in both the construction and critique of claims, they search for ways in which a claim might be wrong and rule out alternative possibilities, which enhances scientific sensemaking (Ford, 2012). Engaging in argumentation can help students understand how scientific knowledge develops (NRC, 2012), encourage deeper understandings of concepts (Zohar & Nemet, 2002), and strengthen their abilities to engage in this practice (McNeill, 2009).

Similar to other researchers (Jiménez-Aleixandre & Erduran, 2008), we define scientific argumentation in terms of both its *structure* and as a *dialogic process*. In terms of *structure*, numerous education researchers have adapted Toulmin's (1958) model of argumentation (Sampson & Clark, 2008). In line with this work, we consider the *structure* of an

argument to consist of a claim about the natural world that is supported by both evidence and reasoning (McNeill, Lizotte, Krajcik, & Marx, 2006). A claim is a statement or conclusion about a question or problem. Evidence includes scientific data such as observations or measurements that support the claim. While evidence provides support for the claim, reasoning justifies how the evidence links to the claim using scientific principles or disciplinary core ideas. The claim, evidence and reasoning framework, reduces the complexity of argumentation (Quintana et al., 2004) and focuses the learner on the relevant task features (Pea, 2004). Furthermore, the structure highlights the types of justifications scientists' value to warrant claims (Sandoval & Cam, 2011).

Argumentation is also a social or *dialogic process* that includes interactions among individuals in which the objective is to persuade or convince one another of a particular claim (Jiménez-Aleixandre & Erduran, 2008). This social process includes both the construction of arguments and the critique of arguments, in which claims as well as their justifications are questioned and evaluated (Ford, 2012). Understanding argumentation as a social practice is essential for the development of classroom norms (Berland, 2011). In classroom instruction, a culture that permits and encourages student-to-student interactions is important for supporting students in dialogic argumentation (Osborne, Erduran, & Simon, 2004). Dialogic interactions enable students to become learners with real agency, rather than just passive receptacles of information (Polman, 2004). This process differs from traditional classroom instruction in which students typically speak directly to the teacher, responding to their teacher's questions and evaluations instead of to their peers (Berland, 2011). Instead, dialogic argumentation discussions shift the goal to collaboratively making sense of phenomena and convincing others of those ideas (Berland & Reiser, 2011). Through this process, students can consider multiple claims as well as revise their ideas based on new evidence and reasoning.

Teachers' Use of Curriculum Materials

To meet the needs of teachers and students around the science practices, such as argumentation, we need instructional materials that address these key learning goals (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). Curriculum materials can be essential in supporting change in classroom instruction because they offer teachers concrete materials aligned with new reform efforts (Powell & Anderson, 2002). The findings from the 2012 *National Survey of Science and Mathematics Education* suggest that curricula in the United States have a substantial influence on classroom science instruction in a variety of ways, from providing text that serve as students' primary reading material to affecting how teachers plan for instruction (Banilower et al., 2013). The fundamental role of curricular resources is to provide teachers with guidance and ideas for instruction through the inclusion of different features such as activities, pedagogical suggestions, and descriptions of common student conceptions (Remillard, 2005).

However, teachers' enactments of reform efforts (Cohen, 1990) and curriculum materials (Brown, 2009) often vary in significant ways. Frequently, teachers deviate from published materials by skipping sections as well as supplementing materials (Banilower et al., 2013). Teachers can focus on superficial aspects, instead of the underlying learning goals (Zohar, 2008). Furthermore, teachers can transform "critical details" in instruction, such as combining old teaching strategies with new ones and altering student activities to become teacher demonstrations (Viennot, Chauvet, Colin, & Rebmann, 2005). These sometimes seemingly small changes can significantly alter the instruction. For example, teachers can change the activity structure of lessons by turning group work into teacher lecturing, which can have a negative impact on students' abilities to engage in science practices (McNeill, Pimentel, &

Strauss, 2013). However, teachers' adaptations of curriculum can also have positive impacts on student learning when they support the development of a classroom culture that aligns with the underlying goals of recent reform efforts (Debarger et al., 2017). For example, while enacting a curriculum focused on argument one teacher added instructional moves to set-up a classroom culture in which the students took ownership of the argumentation norms, critiquing each other's explanations (McNeill, 2009).

Previous research has used different perspectives to examine teachers' enactment of curriculum materials (Davis, Janssen, & Van Driel, 2016). Research related to the fidelity of implementation examines how closely the curriculum user's enactment aligns with the designer's intended design, with the idea that all of the structures and features from the curriculum are adhered to exactly (O'Donnell, 2008). Our work draws from an expanded view of curriculum enactment that considers curriculum use as a design activity in which teachers use materials in unique ways to craft instruction (Brown, 2009). Rich learning environments rely on a variety of different contextual supports to scaffold student learning (Tabak, 2004). There is a dynamic interplay between the teacher, the curriculum materials, and their classroom context, all of which impact curriculum use. Consequently, there is a range of acceptable enactments of a curriculum, rather than one correct way to teach each lesson (Remillard, 2005). Teachers' successful implementation of a curriculum is thus determined by the alignment with the overarching goals of the curriculum, rather than by following specific procedures in a lesson (Davis, Beyer, Forbes, & Stevens, 2011).

Educative Curriculum Materials

Educative curriculum materials that support teacher learning offer promise for promoting changes in classroom instruction that meet the goals of recent reform efforts (Ball & Cohen, 1996; Davis & Krajcik, 2005). Because curriculum materials are specifically linked to teachers' daily classroom instruction, curricula offer a potential avenue for supporting teacher learning situated in their own practice (Putnam & Borko, 2000). For example, educative curricula can provide implementation guidance to illustrate teacher strategies as well as rationales for instructional decisions, explaining why particular approaches are pedagogically appropriate (Beyer, Delgado, Davis, & Krajcik, 2009). Teachers' use of educative curriculum can result in changes in teachers' language use and teaching moves (Arias, Bismark, Davis, & Palincsar, 2016). In light of current reforms, educative supports for disciplinary practices, such as argumentation, may be essential for supporting teachers' knowledge of the practices as well as knowledge of how to support students in achieving these sophisticated learning goals (Davis & Krajcik, 2005). Educative materials can positively impact teacher learning of science practices as teachers interact with the materials as well as their students to enact new reform efforts (Schneider, 2013).

LITERATURE REVIEW

Although argumentation is an essential part of science, authentic argumentation is often lacking in school settings (Osborne, 2010). Science education tends to overemphasize students learning a collection of facts rather than understanding how ideas are developed and transformed over time (Roth & Garnier, 2011). Consequently, teachers need greater support to effectively integrate argumentation into their classrooms (Simon, Erduran, & Osborne, 2006). As a field, we have identified some challenges that teachers face in implementing argumentation (e.g., Crippen, 2012; Sampson & Blanchard, 2012), and have begun developing resources, such as curriculum materials, to provide teachers with support

around argumentation (Cavagnetto, 2010). However, there has been limited work on how teachers use those resources and their decision making about argumentation.

Despite a recent emphasis on argumentation in the research literature, relatively little work has focused on teachers' beliefs and understandings of argumentation (Evagorou & Dillon, 2011). The work that has specifically targeted teachers has found a range of areas in which they need greater support. For example, teachers can view argumentation as less attainable for some students, such as students with low socioeconomic status, English language learners (ELLs), and special education students, rather than seeing it as an achievable goal for all students (Katsh-Singer, McNeill, & Loper, 2016). Furthermore, teachers can have challenges with the structural elements of argumentation such as knowing what counts as appropriate evidence and reasoning to support claims (Crippen, 2012; Sampson & Blanchard, 2012) as well as analyzing written arguments to critique their quality (Sadler, 2006). In addition, teachers can have difficulty analyzing classroom discourse for dialogic interactions (McNeill & Knight, 2013) as well as establishing classroom norms to support a dialogic culture (Alozie, Moje, & Krajcik, 2010). Teachers often need support to develop new knowledge and teaching skills to effectively teach scientific argumentation (McNeill & Knight, 2013). Educative curriculum materials offer one potential avenue for that support. However, teachers' beliefs and understandings can significantly impact teachers' perceptions of curriculum (Davis et al., 2016) and how they enact them in their classrooms (Bryan, 2012).

Specifically, the field has developed curricular units to support students and teachers with this important disciplinary practice. For example, Herrenkohl and Cornelius (2013) examined the enactment of elementary science and history curricula focused on argumentation, which they found supported the development of a classroom community engaged in scientific and historical arguments. Berland and Reiser (2011) utilized three design strategies (i.e., making the epistemic criteria explicit, using complex questions and rich data, and requiring student collaboration) to support students in argumentation writing and talking. McNeill and Pimentel (2010) examined student and teacher discourse during the enactment of a high school urban ecology curriculum that emphasized the importance of justifying claims with evidence and reasoning to support students in argumentation discussion. Across all of these studies, although the curriculum demonstrated some success in supporting students, the research also revealed considerable variation in the teachers' argumentation instruction (Berland & Reiser, 2011; Herrenkohl & Cornelius, 2013; McNeill & Pimentel, 2010). Furthermore, none of these studies explored the teachers' decision-making processes around the curriculum enactment to better understand *why* teachers made these changes around argumentation.

As a field, we have developed recommendations around the design of curricular units and tools for supporting students in disciplinary practices such as argumentation (Cavagnetto, 2010; Quintana et al., 2004), and have identified some areas in which teachers need greater support (Katsh-Singer et al., 2016; Sampson & Blanchard, 2012). However, little is still known about how to successfully design curricula to support teacher use and learning from those materials (Davis & Krajcik, 2005). As Davis et al. (2016) argue in a recent review of the literature about science curriculum materials, relatively little is understood in terms of *why* teachers make the decisions that they do around curriculum use. They suggest that a better understanding of the mechanism underlying teachers' interaction with the curriculum is important to help curriculum developers design materials more effectively. Consequently, in this study we investigated teachers' enactment of curriculum materials as well as their curricular decision making around those enactments for supporting students in scientific argumentation.

METHOD

Curricular Context

This study took place in the context of a pilot of an earth science curriculum in which the teacher materials were delivered digitally on a tablet computer (e.g., iPad). The curriculum was developed by the Learning Design Group at the Lawrence Hall of Science. Building on an elementary integrated science and literacy curriculum called *Seeds of Science/Roots of Reading* (Cervetti, Barber, Dorph, Pearson, & Goldschmidt, 2012), the curriculum utilized a multimodal approach in which students experience science concepts in four modalities: Do-It, Talk-It, Read-It, and Write-It (Pearson, Moje, & Greenleaf, 2010). Furthermore, the curriculum engaged students in the science practices included in the *NGSS* (NGSS Lead States, 2013).

For this study, we investigated the teachers' enactments of two different 6-week units: *Currents and Earth's Climate* and *Plate Tectonics.* These two units were selected because of their emphasis on constructing and critiquing arguments across reading, writing, and talking. In addition, we selected them because they were piloted near the two research teams (one on the east coast and one on the west coast), which enabled us to video record the enactments and interview the teachers. *Currents and Earth's Climate* focused on how differences in density cause currents in the Earth's ocean and atmosphere as well as how air currents, ocean currents, and the water cycle affect regional climates. *Plate Tectonics* emphasized how interactions between tectonic plates cause surface features and events on Earth, and have caused the Earth's surface to change and shift over millions of years. Each teacher piloted one of the two units.

For each unit, we selected two argument lessons for analysis because of their focus on both the structural and dialogic elements of argumentation. In the first lesson, the curriculum suggested that the class read and critique a scientific argument. Specifically, the lesson used a structure for justifying a claim with evidence and reasoning (McNeill et al., 2006) to evaluate the strengths and weaknesses of the argument. The lesson included students identifying and evaluating the components of an argument (i.e., claim, evidence, and reasoning) within the reading to determine the quality of the argument. In the second argument lesson, the curriculum suggested that the class engage in a Science Seminar in which students debate their explanations for a scientific question using evidence collected during previous lessons. The lesson included an activity structure in which the class was split into two groups that were arranged in two concentric circles. While the inner circle engaged in the argumentation, the outer circle observed and provided feedback, and then the groups switched roles. Table 1 provides a summary of the focal argumentation lessons.

To summarize the argumentation educative features in the curriculum, we coded the curriculum using the educative criteria developed by Beyer et al. (2009). Specifically, we focused on their coding of educative supports for pedagogical content knowledge of scientific inquiry, because they aligned with the focus on argumentation. However, since they were not specific for the science practice of argumentation we adapted their criteria for *rationale* and *implementation guidance* to target the structural and dialogic aspects of argumentation included in the curriculum. Specifically, in *Category 1: Description of Argument,* we included their criteria of rationale and added a definition of argument. We analyzed argument structure and argumentation as a dialogic process separately resulting in four subcategories (Table 2). *Category 2: Implementation Guidance* included two subcategories, one focused on common student conceptions and the second on instructional strategies, again adapting them specifically to focus on argumentation. For the six subcategories, we coded each of the four lessons separately. We looked for evidence of

TABLE 1
Summary of Focal Argumentation Lessons

Curriculum Unit	Lesson Focus	Lesson Description
Currents and Earth's Climate	Reading an Argument	• Warm-up: Writing about the phrases *surface currents* and *deep ocean currents*. • Introduce article by talking about the Ice Age. • Read and analyze a scientific argument—How were the deep ocean currents different 18,000 years ago? • Discuss example of an everyday argument—Do video games make you smarter?
	Science Seminar	• Review the purpose and process of a Science Seminar. • Project South America Precipitation Map and remind students of the question—Why is the Atacama Desert the driest place on Earth, with some parts that haven't had any precipitation in hundreds of years? • Group 1 debates their explanations while Group 2 observes. • Group 2 debates their explanations while Group 1 observes. • Reflect on the class participation in the Science Seminar.
Plate Tectonics	Reading an Argument	• Warm-up: Writing three sentences containing one of these words—*argument*, *crust*, and *zone*. • Add everyday and scientific meanings for *argument*, *crust*, and *zone* to the Multiple Meanings Word Chart. • Read and analyze a scientific argument—Why use wax to study rock?
	Science Seminar	• Warm-up: Think about students' arguments to address the question—How will the Indian plate be different in 50 million years? • Review the purpose and process of a Science Seminar. • Group 1 debates their explanations while Group 2 observes. • Group 2 debates their explanations while Group 1 observes. • Reflect on the class participation in the Science Seminar.

the subcategory across the entire lesson including all supporting materials (e.g., lesson description, educative notes). We then coded each lesson as being either a Level 2: present and high quality, Level 1: present and low quality, or Level 0: not present (see Supporting Information Materials for coding scheme).

Each lesson was independently coded by three members of the research team—the first author, a graduate research assistant, and an undergraduate research assistant. The team met and discussed their codes and evidence for each category. Any disagreements were resolved through discussion with feedback from the entire research team (one faculty member, three

TABLE 2
Analysis of the Four Argument Lessons

	Currents Reading Argument	*Currents* Science Seminar	*Plate Tectonics* Reading Argument	*Plate Tectonics* Science Seminar
Category 1: Description of argument				
1A. Argument structure	2	1	2	1
1B. Rationale for structure	1	0	0	0
1C. Argumentation as a dialogic process	1	1	1	1
1D. Rationale for dialogic process	0	1	0	2
Category 2: Implementation guidance				
2A. Common student conceptions	2	0	1	0
2B. Instructional strategies	2	1	2	1

2, present and high quality; 1, present and low quality; 0, not present.

doctoral students, and two undergraduates). In addition, the results of the analysis were shared with the curriculum designers who offered important perspectives in making sense of the results.

Our analysis of the curriculum suggests that all four lessons included a specific focus on argumentation. The curriculum defined, offered a rationale, and provided implementation guidance for both the structure of an argument and for argumentation as a dialogic process (see Table 2). In both units, the lesson on reading and critiquing an argument included more of a focus on the structure of an argument, while the Science Seminar lesson included more of a focus on argumentation as a dialogic process. These foci aligned with the overarching goals of each of the lessons. Considering this curricular context with a specific focus on argumentation, we were interested in the variation in the teachers' enactments of the lessons, and the teachers' rationales behind their curricular enactments.

Participants

Across the United States, sixty-five teachers piloted the curriculum materials. This study specifically focuses on 10 pilot teachers, selected based on their vicinity to the two research teams, who taught either fifth- or sixth-grade science. One limitation of this study is that all of the teachers were interested in enacting a reform-oriented curriculum. Consequently, they may not be representative of a typical middle school science teacher. However, the teachers had a range of backgrounds from one first-year teacher to one teacher with more than 20 years of teaching experience (see Table 3). Furthermore, the teachers had various teaching certifications as well as backgrounds in science. The majority of the teachers either taught only science or science and one other subject (e.g., math or art) with the exceptions of Ms. Lynn and Ms. Allen who taught a broader range of subjects.

The teachers taught in a range of school contexts. Table 4 provides information about the school and classroom contexts. The schools included two religious private schools, one

TABLE 3
Teachers' Backgrounds

Teacher	Type of Teaching Credential	Highest Level of Education	Years of Teaching Experience	Classes Taught
Ms. Lynn	Multisubject (elementary)	BA	6–10	Science, mathematics, art, computer skills, religion
Ms. Brennan	Multisubject (elementary), single subject (secondary), Montessori (preprimary)	BA	More than 20	Science, art
Ms. Allen	Multisubject (elementary)	BA	1	All subjects
Ms. Richardson	Single subject (secondary)	MA	11–15	Science, mathematics
Ms. Owens	Multisubject (elementary)	MA	6–10	Science, mathematics
Ms. Klein	Multisubject (elementary), single subject (secondary)	MA and MS	11–15	Science
Ms. Norman	Single subject (secondary)	BA	11–15	Science
Ms. Kelly	Single subject (secondary)	MA	6–10	Science
Mr. Reyes	General science (6–8), middle school math/Spanish	EdD	11–15	Science
Mr. Carter	Single subject (secondary)	MS	11–15	Science, administration

charter school (i.e., publically funded independent school), and five public schools. The five public schools came from two different school districts. For the two religious private schools, we were unable to obtain information about the student population. The rest of the student information reflects a diversity of backgrounds in terms of percent of students eligible for free and reduced lunch, percent of non-White students, and percent of ELLs.

Data Collection

This study examined two data sources: classroom videos and teacher interviews. As we mentioned previously, the videorecorded lessons included one lesson in which students read and critiqued a written argument and a second lesson in which students engaged in a Science Seminar (see Table 1 for details). After each lesson, the teacher was interviewed for approximately 30–45 minutes using a semistructured interview protocol (See Supporting Information Materials) about their beliefs around argumentation and their curricular

TABLE 4
School and Classroom Context

Teacher	Type of School	District	Grade of Students in Pilot	Class Size	% of Free and Reduced Lunch	% of Non-White	% of ELL
Ms. Lynn	Private A (religious)	N/A	6	21–25	N/A	N/A	N/A
Ms. Brennan	Private B (religious)	N/A	6	31–35	N/A	24	N/A
Ms. Allen	Public C	1	6	26–30	54	75	33
Ms. Richardson	Charter D	N/A	5	26–30	81	98	56
Ms. Owens	Charter D	N/A	6	26–30	81	98	56
Ms. Klein	Public E	2	6	21–25	89	88	35
Ms. Norman	Public F	2	6	26–30	86	95	31
Ms. Kelly	Public F	2	6	21–25	86	95	31
Mr. Reyes	Public G	2	6	21–25	29	45	9
Mr. Carter	Public H	2	6	26–30	64	76	15

N/A, not available or not applicable.

decision making when enacting the argumentation lesson. The goal of the interview was to develop an understanding of why the teacher chose to enact the lessons in particular ways. All interviews were transcribed for analysis.

Data Analysis

In our analysis of the data, we were interested in the similarities and differences in the teachers' instruction and their rationales behind enactment decisions. Consequently, we conducted a cross-case analysis using both data sources to develop rich descriptions and to examine the processes and outcomes across the multiple cases to develop more powerful explanations of the phenomenon of interest (Miles & Huberman, 1994). There are limitations in using a comparative case study approach as it does not allow for causal claims or generalizations for all science teachers; however, it offers rich potential explanations for further study.

Video and Interview Analysis. To analyze the classroom videos and teacher interviews, we developed coding schemes using our theoretical framework as well as an iterative analysis of the data (Miles & Huberman, 1994). The coding scheme for the videos included three categories: (1) argument structure, (2) argumentation as a dialogic process, and (3) instructional strategies. The first two categories were informed by our definition of argumentation including a focus on the structure of an argument and argumentation as a dialogic process (Jiménez-Aleixandre & Erduran, 2008). These categories each included three subcategories: the first focused on how the teacher defined or discussed that aspect of argumentation; the second focused on whether the teacher provided a rationale; and the third examined the students' engagement in that aspect of argumentation. For the first two subcategories, we were interested in capturing the quality of the teacher moves in terms of how they were framing and supporting argumentation (Berland & Hammer, 2012). Specifically, we drew on research discussing the importance of the teacher providing a structure for the practice (Quintana et al., 2004) and providing a rationale for the practice

(Kuhn, Black, Keselman, & Kaplan, 2000) to examine how the teacher both introduced and provided a purpose for the structural and dialogic goals. The third subcategory focused on the quality of the students' engagement in argumentation. The last category, instructional strategies, captured the teachers' use of other instructional strategies (e.g., such as modeling, everyday examples, or sentence starters) that would support the structural and/or dialogic goals of argumentation. For each lesson, we coded each subcategory as present and high quality, present and low quality, or not present. Table 5 includes a summary of the coding scheme for the high-quality codes (see Supporting Information Materials for complete codes and examples of the codes). In coding each lesson, we looked for instances of the codes across the entire lesson, time stamping and transcribing any relevant sections.

The development of the coding scheme for the interviews included a focus on two categories: Category 1: knowledge of argumentation and Category 2: curricular decision-making factors for argumentation instruction. In terms of knowledge, we focused on the teachers' discussions of argument structure and argumentation as a dialogic process to align with our coding of the quality of the argumentation instruction. We were interested in the accuracy and depth at which they discussed these ideas, so we coded each subcategory as present and high quality, present and low quality, or not present. Table 6 provides a description of the high-quality code (See Supporting Information Document for complete coding scheme and examples of the codes).

In terms of decision-making factors related to the enactment of the argumentation instruction, we developed an initial list of factors based on the research literature, such as the role of curriculum (McNeill, 2009) and the effect of students' backgrounds on instructional choices (Sampson & Blanchard, 2012). In addition, we engaged in open coding looking for emergent codes for each teacher by considering recurring ideas and language in the data about the factors that impacted their instruction (Marshall & Rossman, 1999). As will be illustrated in the Results section, a number of the key factors arose from these emergent codes. For Category 2, we only coded for the presence or absence of each factor. To be coded as present, a factor needed to come up multiple times over the course of the interview. Table 7 provides a summary of these codes. For both categories (Tables 6 and 7), we analyzed the entire interview across all questions, because we found that evidence of both teachers' understanding of argumentation and the factors that impacted their decisions reoccurred as they revisited ideas in more depth. Sometimes the more open questions (e.g., Can you talk me through how you prepared for today's lesson?) resulted in a more in-depth discussion of their decision making, then the more targeted questions (e.g., In what ways did the curriculum materials including the lesson plan and educative notes impact your teaching of this argumentation lesson?)

All videos and interviews were independently coded by four members of the research team—the first author, two graduate research assistants, and one undergraduate research assistant. We focused on one case study teacher at a time to develop a rich understanding of that teacher's practice and decisions around argumentation. We used the coding of both data sources to develop the case studies for each teacher. The case studies included two subsections. The first section focused on the quality of the argumentation instruction and relied on the video analysis. The second section targeted the curricular decision-making factors and focused on the interview transcripts. After independently coding the videos and interviews for each teacher, we conducted case analysis meetings in which the entire research team met to discuss the codes and the evidence for the codes. The discussions in the meetings entailed collectively revisiting videos and transcripts to look for confirming and disconfirming evidence to challenge, refine, and enhance our coding of each teacher (Erickson, 1986). These meetings often involved rich discussions of the other emergent

TABLE 5
Argumentation Coding Scheme for Curriculum Enactment

Category	Description of High-Quality Code
1A. Teacher defines argument structure	The teacher describes an argument structure as a claim or explanation about the natural or designed world that is supported or critiqued using evidence and scientific reasoning. Teacher discusses that students' arguments should include both scientific data and scientific knowledge to support the claim.
1B. Teacher provides a rationale for structure	The teacher provides multiple reasons for why the structure of argument is important. Examples of reasons could include: • Is a key scientific practice • Is an important aspect of disciplinary literacy across content • Is a 21st century skill for both inside and outside the classroom • Supports learning science content • Develop epistemological understandings
1C. Students construct or critique arguments using structural elements	Numerous students provide or critique the quality of the argument(s) taking into consideration the quality of the claim and evidence or justification for that claim. This code is given when the structure of the argument seems to be a part of the classroom norms in terms of the students' participation.
2A. Teacher defines argumentation as a dialogic process	Teacher describes argumentation as including both: • convincing or persuading an audience about the strength of a particular claim over other claim(s). • includes student-to-student interactions characterized by students listening to each other, building on each other's ideas and critiquing ideas, debating ideas.
2B. Teacher provides a rationale for argumentation as a dialogic process	Teacher provides multiple reasons for why the process of argumentation is important. Examples of reasons could include: • Science is a discourse that includes science talk • Science is a social process in which scientists debate knowledge claims • Students need to actively engage in this type of science talk to gain greater proficiency in science (science content) • Engaging in this social process may change students' understanding of science or views about science
2C. Students engage in argumentation as a dialogic process	The students in the classroom engage in argumentation that includes the students: • convincing or persuading an audience about the strength of a particular claim • includes student-to-student interactions such as students listening to each other, building on each other's ideas, critiquing ideas, debating ideas This should include multiple students engaging in student-to-student interactions building on the ideas of their peers.
3A. Teacher uses instructional strategies to support students in argument	Uses an instructional strategy for supporting students in argument *in depth*. The instructional strategy includes an example or description that is content or lesson specific to help illustrate what this looks like in a particular context. For example, an in depth instructional strategy could include modeling a scientific argument and clearly identifying and critiquing the different components, such as the claim and evidence, as well as discussing how those components impact the overall quality of the argument.

TABLE 6
Coding Scheme for Teacher Interviews: Knowledge of Argumentation

Category	Description of High-Quality Code
Argument structure	• Describes an argument structure as a claim or explanation about the natural or designed world that is supported or critiqued using evidence and scientific reasoning. • Provides definitions of key terms such as a claim is a conclusion, evidence is scientific data, and reasoning is the justification for why the evidence supports the claim using scientific knowledge or principles.
Rationale for structure	Provides multiple reasons for why the structure of argument is important. Examples of reasons could include: • Is a key scientific practice • Is an important aspect of disciplinary literacy across content • Is a 21st century skill for both inside and outside the classroom • Supports learning science content • Develop epistemological understandings
Argumentation as a dialogic process	Describes argumentation as including both: • convincing or persuading an audience about the strength of a particular claim over other claim(s) • includes student-to-student interactions such as students listening to each other, building on each other's ideas and critiquing ideas, debating ideas
Rationale for argumentation as a dialogic process	Provides multiple reasons for why the process of argumentation is important. Examples of reasons could include: • Science is a discourse that includes science talk • Science is a social process in which scientists debate knowledge claims • Students need to actively engage in this type of science talk to gain greater proficiency in science (science content) • Engaging in this social process may change students' views of science.

factors (see Table 7) that impacted the teacher's curricular enactment. As will be illustrated in the Results section, these factors were more complex than the initial list we developed from the literature. Engaging multiple coders in the process increased the reliability of our interpretations as we developed and tested rival interpretations of the data (Miles & Huberman, 1994).

This collective process resulted in a summary document for each case including the final codes and specific examples from videos and transcripts to support those codes. The first author used these documents to develop a detailed case study for each teacher that captured the complexities within the classroom (Stake, 2000). The goal of the detailed case studies was to develop a narrative that accurately depicted the most important features of each case study with respect to the teacher's argumentation instruction and the curricular decision-making factors related to their instruction (Stake, 2000). After the first author developed each case study, the second author, who was one of the original coders of the videos and interviews, read and evaluated each case study keeping in mind the coding and decisions of the research team during the case analysis meetings. Overall, the case studies were consistent with her interpretations. The few discrepancies were in terms of what specific examples to use to best illustrate the case. When the first and second author had different

TABLE 7
Coding Scheme for Teacher Interviews: Curricular Decision-Making Factors

Category	Description of Code
Other educational goals	Discusses how argumentation supports students in other educational learning goals such as supporting language arts
Curriculum materials	Discusses how the curriculum had a major impact on their inclusion of argument
Students	Discusses how the students' backgrounds or abilities had a major impact on argumentation
Standards and tests	Discusses how standards and tests had a major impact on their instruction (either in a positive or negative way)
District, administrators, or teachers	Discusses how initiatives in their school district, administrators, or other teachers had a major impact on their argumentation instruction
Self-efficacy	Discusses how their self-confidence has a major impact on their argumentation instruction
Knowledge	Discusses how their knowledge of argument (either lack of or that they feel like they have a lot) had a major impact on their instruction
Other emergent factors	Add other emergent factors that appeared to have a major impact on their argument instruction (open coding from the teachers' responses)

opinions, these opinions were brought back to the entire research team for resolution. The final detailed case studies were between seven and eight single-spaced pages for each of the 10 teachers.

Cross-Case Analysis. To examine the patterns across the 10 case study teachers, we conducted a cross-case analysis in which we inspected the cases to determine if they fell into clusters or groups that shared certain features (Miles & Huberman, 1994). To facilitate this process, we developed a summary table highlighting the key aspects of each case study. In developing the table, we ordered the teachers along a dimension to facilitate the process of looking for patterns (Miles & Huberman, 1994). Specifically, teachers were ordered based on the quality of their argumentation instruction from higher level instruction to lower level instruction. None of the teachers were considered to have completely exemplary instruction in terms of argumentation, because of challenges with either the structure or dialogic process. After ordering the teachers based on quality of argumentation instruction, we then examined the table for patterns in terms of the curricular decision-making factors related to their argumentation instruction. From this analysis, there appeared to be three decision-making factors that repeatedly emerged in relation to the teachers' curricular enactments. In presenting case studies, there is a tension between providing sufficient detail to accurately represent the complexities of the case and considering the needs of the reader to have the important findings highlighted (Stake, 2000). Consequently, we decided to focus the summary table on those three decision-making factors that recurred across the teachers in terms of their enactment of the argumentation curriculum to highlight these findings for the reader.

RESULTS

Across the 10 teachers, we observed a wide range in their enactments of the argumentation lessons for both the argument structure and dialogic process. Table 8 provides a summary for 10 teachers ordered from higher quality argumentation instruction to lower quality argumentation instruction. Although all of the teachers were clearly teaching the same lessons (e.g., all teachers used and discussed the argument reading), they made different decisions in terms of language use, activity structures, and classroom norms. Furthermore, there were differences in the students' engagement in argumentation in terms of how they supported their claims with evidence as well as questioned and critiqued the ideas of their peers. Because the argumentation instruction was coded for two dimensions (i.e. structure and dialogic process), there are a number of instances when we debated where a teacher should be placed in the table. For example, Ms. Klein's instruction was stronger in terms of argumentation as a dialogic process, while Ms. Kelly's instruction was stronger in terms of the structure of an argument. However, the extremes in the table are clearly different in terms of argumentation instruction.

After ordering the teachers in terms of the quality of their argumentation instruction, we then examined the curricular decision-making factors to look for trends. Specifically, the three factors that emerged from the teachers' discussion of their decision-making included (1) teachers' understanding of argumentation as an epistemic practice, (2) teachers as curriculum users, and (3) teachers' prior teaching experiences. There were other factors mentioned by a subset of the teachers, such as two teachers discussed classroom management. We decided to prioritize those elements included in all of the teachers' decision making in terms of the enactment of the argumentation lessons.

We present two teachers' case studies, the teachers highlighted in gray in Table 8, to illustrate the trends for the three decision-making factors. We decided to present the extreme cases because they more clearly illustrate the conceptual factors the teachers discussed around their decision making while enacting the curriculum (Miles & Huberman, 1994). Specifically, we focus on the teacher with the lowest quality argumentation instruction, Ms. Brennan, and the teacher with the second highest argumentation instruction, Ms. Norman. We chose not to include the teacher with the highest quality argumentation instruction, Ms. Allen, because the factors she discussed were different than the other teachers. She did not describe as extensively as the other teachers her prior teaching experiences and was more focused on English Language Arts, which may be the result of her different background. Ms. Allen was also the only first-year teacher and the only teacher who taught her students all day for every subject. The other teachers had at least 6 years teaching experience and the majority were science specialists or taught science and one other subject (e.g., math). Instead, we selected Ms. Norman because the factors that she discussed in relation to her decision making were more representative of the other higher quality instruction teachers.

Ms. Norman: High-Quality Instruction and Reflective Curriculum User

Argumentation Instruction. Ms. Norman's instruction included high-quality argumentation in both lessons. Her instruction was particularly strong in terms of using the structure of an argument as a tool to support productive classroom discourse. When engaged in constructing and critiquing arguments, both Ms. Norman and her students supported and critiqued claims with evidence (e.g., data) and scientific principles. During the Reading an Argument lesson in *Currents* (see Table 1), Ms. Norman had the students evaluate an argument in the curriculum, which addressed the question, *Do video games make you smarter?* While discussing the argument with her students, Ms. Norman discussed how the structure

TABLE 8
Summary of 10 Case Study Teachers

		Argument Structure	Dialogic Process	Decision-Making Factors
Intermediate Quality Instruction ←——→ Higher Quality Instruction	Ms. Allen	• Used CER language, but vague • Provided a rationale—connected to ELA • Frequent student use of structure	• Discussed student-to-student interactions and persuasion • Provided a rationale—may change students' minds • Frequent student-to-student interactions	• An understanding of argument, but limited in terms of science • Followed the curriculum, but also used it to support existing norms across subjects • Limited prior teaching experiences and predominately in ELA
	Ms. Norman	• Used CER language and defined components • Provided a rationale—Structure makes it more persuasive or stronger • Frequent student use of structure	• Discussed student-to-student interactions and persuasion • Provided multiple rationales—scientists engage in this process and may change students' minds • Limited student-to-student interactions	• An understanding of argument • Followed the curriculum, but was a reflective and critical user • Prior teaching with a focus on questioning students to encourage them to support and change their ideas
	Ms. Richardson	• Used CER language, but vague • Provided a rationale—connection to scientists • Limited student use of structure	• Discussed persuasion • Provided multiple rationales—scientists engage in this process, may change students' minds, increase understanding of content • Limited student-to-student interactions	• An understanding of argument • Followed curriculum, but also learned from the curriculum • Prior teaching and background in science focused on science as a practice
	Ms. Owens	• Used CER language, but vague • No rationale • Limited student use of structure	• Discussed student-to-student interactions and persuasion • Provided a rationale—may change students' minds • Frequent student-to-student interactions	• Different understanding of argumentation than curriculum • Used the curriculum as a guide that she adapted • Prior teaching with a focus on discussion
	Ms. Lynn	• Used CER language, but vague • No rationale • Very limited student use of structure	• Discussed student-to-student interactions • Provided a rationale—may change students' minds • Limited student-to-student interactions	• Limited argument understanding • Desire to closely follow the curriculum • Prior teacher-centered teaching

(*Continued*)

TABLE 8
Continued

		Argument Structure	Dialogic Process	Decision-Making Factors
Lower Quality Instruction ←——→ Intermediate Quality Instruction	Ms. Kelly	• Used CER language and defined components • No rationale • Limited student use of structure	• Discussed persuasion • Provided a rationale—may change students' minds • No student-to-student interactions	• Understanding of argument as a structure, but not as a process • Used the curriculum as a guide that she adapted • Prior teaching experiences focused on structure in her school district
	Ms. Klein	• Used CER language, but vague • No rationale • Very limited student use of structure	• Discussed student-to-student interactions and persuasion • No rationale • Frequent student-to-student interactions	• Different view of argumentation as literacy and not science • Used the curriculum as a guide that she adapted • Prior teaching focused on doing science and content, not discourse
	Mr. Reyes	• Used CER language and defined components • No rationale • Limited student use of structure	• Only discussed student-to-student interactions • No rationale • No student-to-student interactions	• Understanding of argument as a structure, but not as a process • Used the curriculum as a guide that he adapted • Prior teacher-centered teaching with a focus on using questions
	Mr. Carter	• Used CER language, but vague • No rationale • Very limited student use of structure	• Discussed student-to-student interactions and persuasion • No rationale • Limited student-to-student interactions	• Limited argument understanding • Used the curriculum as a guide that he adapted • Prior teacher-centered teaching with the teacher as an entertainer
	Ms. Brennan	• Used CER language, but vague • No rationale • Very limited student use of structure	• No definition of process • Provided a rationale—may change students' minds • No student-to-student interactions	• Limited argument understanding • Desire to closely follow the curriculum. • Prior teacher-centered teaching and focus on outcomes

CER, claim, evidence, and reasoning; ELA, English Language Arts.

of an argument, such as data and scientific knowledge, could be used to justify your claims in science:

> *Your data comes from these observations from an experiment and you have to make sure that you set-up the experiment in a controlled way so that you can see what is creating the change. All right. This is something we have started to talk more about lately—where not only do you need data, but you need scientific knowledge to support your claim. So these are the facts, the ideas, the concepts that have been developed over time by scientists doing experiments over and over and building up the knowledge.*

In this quote, Ms. Norman talked about using data and what counts as data to support a claim. Ms. Norman also provided a rationale for the structure, discussing how evidence and scientific knowledge could be used to critique an argument or to make an argument stronger or more persuasive. For example, in this lesson she said to the class before reading an argument, "We are going to do this new thing where we really think critically about what constitutes quality evidence." After critiquing the argument, she talked to the class about how to make it stronger, "We are going to improve our argument by adding in data . . . Does anybody have any scientific knowledge that they know about that we could use to back up the data to make a stronger argument?" Ms. Norman made visible to her class a structure that could be used to construct and critique high-quality arguments. Furthermore, in the Science Seminar lesson she discussed how arguments could "Convince someone . . . If you write an argument, you could actually influence someone making a choice." Ms. Norman provided her class with a rationale and structural model for argumentation, which the students then used when they constructed and critiqued arguments.

During the Science Seminar for the *Currents* unit, both Ms. Norman's and the students' use of the structure was prevalent throughout the discussion as they considered different claims. Ms. Norman also introduced the idea of argumentation as a dialogic process before the activity:

> *Here are our goals. We want to use evidence. We want to listen to one another. You are going to have a chance to respond to each other. And I hope to agree and disagree.*

In this quote, Ms. Norman encouraged the students to argue with each other, which as shown in the transcript below, she reiterated at the beginning of the discussion. During the Science Seminar, the students addressed the question—Why is the Atacama Desert the driest place on Earth, with some parts that haven't had any precipitation in hundreds of years?

> *Matarra: I think that the reason why it is dry is because it is near cold currents, because on the map on page 13 it shows that the Peru Current is cold and it is close to the Atacama Desert. But then again, right near it, it gets some rain. But it might rain there and then when it gets to the Atacama Desert it is not – it just has one drop of rain.*
>
> *[Students raise hands and look at Ms. Norman.]*
>
> *Ms. Norman: Listen you can argue and discuss with each other. I am on the outside of the fishbowl right now. All right. So you can respond.*
>
> *Bryan: Also, I think that the Andes Mountains [refers to map] might be creating the rain shadow effect on the Atacama dessert um so like all the water vapor and something can't get there.*

Susannah: I agree with Bryan, because like the mountains they like, they like – may be like blocking the water

Diana: I disagree that they might be like blocking, because clouds go like higher than the mountains. But they can – the clouds might get tired and rain on the Andes Mountains

Bryan: I also agree with what Matarra said about the current being cold. Because like the cold water won't evaporate easily so they won't have water vapor to condense.

Ms. Norman: Did everyone hear that one?

Students: No

Ms. Norman: Say that again Bryan.

Bryan: Um I agree with Matarra that it is also because of cold currents, because like um - the water will be harder to evaporate so like it won't condense into clouds because there will not be much water vapor.

Ms. Norman: Why is the water harder to evaporate?

Bryan: Because it is cold.

Ms. Norman: How do you know that? What is the evidence?

Bryan: Right here [points to map] on page 13.

During this discussion, students used the structural elements of an argument to support their ideas as well as critique alternative explanations. For example, Matarra started the conversation by offering the claim "it is dry because it is near cold currents" and then referred to some evidence on the map. Bryan then brought an additional claim that the mountains may be impacting the dryness of the Atacama Desert, also referring to the map as evidence. After these two initial claims were introduced, the students tried to make sense of them using their understandings of the science content, such as "the rain shadow effect."

After the first few students shared, Ms. Norman interjected and began asking guiding questions, which continued throughout the rest of the first group's discussion. In these questions, she pushed students to use evidence (e.g., What is the evidence?) and explain their reasoning (e.g., Why is the water harder to evaporate?). Ms. Norman's use of questioning was a frequent strategy in both lessons to help her students use evidence and reasoning to both support and critique claims in science. Unfortunately, after the teacher's interjection, the students all looked to Ms. Norman to lead the discussion, and she played a dominant role in the rest of the discussion. The students then had fewer opportunities for dialogic argumentation in which the students engaged in student-to-student interactions including both building on and critiquing the ideas of their peers. Consequently, although we coded Ms. Norman's argumentation instruction as higher than the majority of the teachers, it is not ideal because the rest of the Science Seminar included limited student-to-student interaction and did not exemplify the dialogic aspects of this science practice.

After the Science Seminar, Ms. Norman asked the students to reflect on the quality of the discussion during the seminar. During this discussion, one of the students brought up that he thought there was a lack of reasoning in the conversation.

Mario: Some people they had like evidence, but like no reasoning.

Ms. Norman: Oh. Say more about that. You said they had evidence, but what would you have wanted them to do with the reasoning part?

Mario: Well, explain how it connected with the claim.

Ms. Norman: Ok. So even if their evidence was good, you did - you felt like they did not make the connection for you as a listener?

In his comments, Mario identified a lack of reasoning and explained that he felt that students were not connecting their evidence to their claim, offering a general definition of what he felt counted as reasoning. This suggests that not only were students using the structure during discussions, but they also had metaknowledge for the practice norms (Schwarz et al., 2009) around argumentation in their classroom. The teacher and students' use of the language during the two lessons suggests that the language and structure were part of the classroom norms in terms of how they constructed and critiqued arguments. However, argumentation as a dialogic process was of lower quality because of the limited student-to-student interaction.

Curricular Decision-Making Factors. Three major curricular decision-making factors emerged from the interviews in relation to Ms. Norman's argumentation instruction: (1) using her understanding of argumentation as an epistemic practice (rather than understanding only surface level features), (2) being a critically reflective curriculum user, and (3) problematizing her prior teaching experiences with a focus on questioning students.

In terms of her understanding of scientific argument, in both interviews she demonstrated knowledge of both the structure and purpose of argumentation. For example, when talking about the first lesson and the video game example, she discussed how claim and evidence are easier for her students, as well as herself, compared to reasoning. She stated, "I felt like they were successful in terms of evidence, and claim. But not reasoning. And that, that parts coming next and that is the part personally I struggle with, and that the students struggle with." She then went on to discuss how the claim, evidence, and reasoning were represented in the presentation slides and how that representation helped her understanding of reasoning:

Yes, what uhm, the thing I love, in that paragraph where they color coded, and then they turned the basic chunks of data and scientific knowledge then they show you how to turn it into a paragraph. That really helped me a lot. Again like I'm saying like I feel like I'm good at the claim and evidence part, but I feel like that paragraph pulled it all together. So it took the claim and the evidence and it added in the reasoning and the explaining in a way that makes it structural.

In this example, Ms. Norman talked about how the curriculum helped her reflect on and clarify her own understanding of reasoning. Interestingly, although she discussed refining her understanding of reasoning, she does not discuss developing a richer understanding of evidence, which can also be challenging for teachers in terms of when and how data become evidence.

Beyond defining the structural elements of an argument, Ms. Norman connected the construction of arguments with these components to the questioning and critiquing of arguments. She provided a more global rationale for why argumentation is important for

developing a stronger understanding of science ideas. For example, in the same interview about the first lesson she explained:

> *. . . but you know like in any good argument, like that you're having with a friend, and someone says "really, why do you think so?" or "where'd you get that information?" or you know, just that kind of pushback . . . I'll say something and someone will disagree with me, and they won't say "no that's wrong" they'll just ask another question and I'll be like "oh yeah, I don't know how in that instance how that would work" so then it makes me think.*

In both of her interviews, Ms. Norman continually came back to this idea of questioning and critiquing ideas as part of the process of argumentation. The structural elements were not an end in themselves, but part of a larger process that encourages the questioning and revising of existing ideas about the world.

In terms of the argumentation process, Ms. Norman also seemed aware that her enactment of the Science Seminar did not include the dialogic aspects such as the student-to-student interaction and debate described in the curriculum. For example, in terms of discussing how she introduced the lesson, she stated:

> *I didn't launch it the best way because they were all looking at me, I didn't really want them to look at me. I wanted them to have the discussion amongst themselves and so I have to think about how I do that with the other classes. So that I don't- I don't want to be who they're directing this to I want them to be talking to each other more.*

She discussed how she wanted the students to be talking more directly to each other. Later in the interview, she came back to this point and provided suggestions of how she might teach this lesson differently in the future. For example, one strategy she suggested was that she could have told the class, "Listen, for the first five minutes of the discussion I'm not going to say anything. I'm just gonna be- I'm just gonna be an observer and a listener too." Her suggestion of not talking for 5 minutes has potential to support students in greater dialogic interactions and suggests she had an understanding of argumentation as a student-driven process.

Another factor that may have impacted her enactment was her desire to follow the curriculum, but in a reflective and critical way. For example, she discussed

> *. . . like I said I tried to stay true to it for the sake of just going through the curriculum the way they want us to. Uhm, the, a lot of the questioning is not from them. I do not follow their script 100%. And because I don't feel like it really captures like the give and take that goes on in discussions, in, in a classroom.*

Here, she discussed how she did follow the lesson and intended, "to stay true," but she did not say quotes verbatim from the curriculum. Rather, she used her own questioning strategies and phrases with her students. Thus, she used the curriculum, but in a reflective and critical way.

Ms. Norman's prior teaching experiences may have had both positive and negative impacts on the quality of her argumentation instruction. In terms of argument as a structure, her previous teaching around the practice and use of questions may have been an asset to her enactment of the curriculum. However, one possible reason that the student-to-student interactions were more challenging for her may stem from her use of questions. She frequently talked about her use of guiding questions in her prior teaching to encourage

greater student critical thinking and reflection. For example, in the first interview she talked about her use of questions stemmed in part from a book she read, *The Skillful Teacher.* She said:

> *The Skillful Teacher is a really good source that I've used to developing how you question in a way that's challenging, that doesn't give things away, but that doesn't give the answer away. And it's that higher order thinking.*

Ms. Norman frequently brought up this idea of using questions to encourage student thinking.

Overall, Ms. Norman's instruction exhibited many high-quality instances of argumentation instruction. Her reflective use of the curriculum, such as her connections to how reasoning has been challenging to both herself and her students, may have helped support that argumentation instruction. However, her prior teaching experiences may have detracted from the enactment of argumentation as a dialogic process, because of her focus on questioning students herself rather than allowing them to engage in student-to-student interactions.

Ms. Brennan: Low Quality Instruction and Nonreflective Curriculum Follower

Argumentation Instruction. Ms. Brennan's instruction included limited instances of argumentation with those existing instances exhibiting low quality. In terms of the structure, she used the language of claim, evidence, and reasoning at times, but did not clearly define the terms or provide a rationale. Furthermore, her students rarely supported or critiqued arguments appropriately utilizing these elements. For example, in the Reading the Argument Lesson in *Plate Tectonics* (see Table 1), she asked students to identify the claim and evidence in the reading. Specifically, she asked the students to place an asterisk next to every piece of evidence. After she introduced the task, she told the class, "I am going to be looking. I am going to be looking at your papers and I am going to be counting the evidence that you find." As the students worked, Ms. Brennan walked around the room and could be heard making statements such as, "It looks to me like there is a lot of evidence to be found" and "I am seeing lots of asterisks. Oooh. I am liking that." She never specifically defined evidence for students; furthermore, she never questioned a student about whether something they placed an asterisk next to actually counted as evidence. Rather, her actions suggested that the more asterisks the better, regardless of what text they were placed next to. Furthermore, as she walked around the room, one student asked about the difference between evidence and reasoning:

> *Sam: What is the difference between this and this? Wouldn't they be pretty much the same? [Points to paper with parts of an argument]*
>
> *Ms. Brennan: A claim is -*
>
> *Sam: I mean the second and the third one.*
>
> *Luca: Reasoning is what supports the claim –*

Ms. Brennan: Well, that is, that is, that is relevant in that it is a significant observation, but is that relevant to making it a good model for rocks? The first one is absolutely. Ok. All right. Ladies and gentleman if I could have your attention.

Ms. Brennan's response to the student is unclear. Also, instead of allowing the student to ask further questions or asking the student a question about his understanding, she called the class together and started them on a new task. Consequently, although she told the class that an argument consists of claim, evidence, and reasoning, she did not offer them an explanation of what these terms mean. Furthermore, during this first lesson, the students did not use the structural language in either critiquing the argument or in constructing their own arguments. The only examples of structural elements that appeared in the student talk were when the students asked Ms. Brennan about a meaning of a term, such as in the previous example.

During the Science Seminar in *Plate Tectonics*, the structural elements of argumentation continued to play a limited role and there were no instances of dialogic student-to-student interactions. Ms. Brennan significantly altered the argumentation lesson with students formally presenting their ideas in the front of the room. She framed the task differently than the dialogic goals presented in the curriculum. To set up the Science Seminar, she did split the students into two groups with half the class in an inner circle and the other half of the class in an outer circle. But instead of having the inner group talk directly to each other, she had one student at a time come up to the front of the room from the inner circle and present their argument. The excerpt below is from the beginning of the Science Seminar:

Ms. Brennan: Elena why don't you come on up. Ok. And you guys be attentive. Guys this is a little bit different than a presentation where someone – this is, this is um a give and take where you are going to be um listening. The inner circle as well is going to be able to – um as they come up – when they come up they will give their evidence for their part, but we can't clap between speakers. You're engaged and listening. It is like as if you were a grown-up and you were going to a workshop. That is exactly what it is like. Ok. Elena.

Elena: Well, I thought that the um Indian plate would get bigger over 50 million year period because of spreading zones which could easily spread the plates apart and make them wider.

Ms. Brennan: Ok. Alright. [Elena sits down]. Ok. I am going to need um – why don't you go ahead. Once this starts, why don't you come on up. Jordan why don't you come next. [Jordan stands up]. And I am just going to move this right over here so you guys can go in and out [Ms. Brennan moves iPad]. Ok.

Jordan: I thought that um that the Himalayans would get taller, because when the plates like started crashing into each other – this one is going in this direction [Jordan points to the map] and it should make it bigger.

Ms. Brennan: Ok. [Jordan sits down]. Thank you very much. Another person. Come on up.

The "Science Seminar" continued in this fashion with one student standing up in the front of the room and presenting their idea and then sitting down. After everyone in the inner circle presented, the whole class clapped. Then, the inner circle switched seats with the outer circle and the new inner circle followed the same activity structure with one student presenting at a time. The students never talked directly to each other, never asked each other questions about their arguments and never critiqued the alternative claims. Consequently,

the student engagement in the dialogic argumentation process was coded as not present. In terms of the structure, there were limited instances in which the students supported their claims with evidence that appropriately addressed the overarching question of the lesson—How will the Indian plate be different in 50 million years? For example, in the above transcript, Elena does offer a claim that addresses the question (i.e., "Indian plate would get bigger"), but she does not provide specific data from the maps and other resources to use as evidence for her claim. In contrast, Jordan does offer some evidence from the projected map about the movement of the plates; however, his claim is about the height of the Himalayans and he does not provide an explicit link to the Indian plate.

Curricular Decision-Making Factors. A number of curricular decision-making factors emerged from the interviews in relation to Ms. Brennan's argumentation instruction, including her (1) limited understanding of argumentation as an epistemic practice, (2) desire to closely follow the curriculum, and (3) prior teacher-centered instructional approach.

Throughout both interviews, she talked about her argumentation instruction in ways that did not align with her enactment, suggesting she had a limited understanding of argumentation. For example, in her interview for the Science Seminar, she used the language of claim, evidence, and reasoning, but it is unclear what she meant by these terms. When discussing the students' presentations she stated:

> *I think that they were successful in as much as they were the beginning, by having to present out loud, using the language of the discipline, I think it brought clarification and clarity, both to the presenters and to the listeners of what they were trying to do, specifically, having the claim and trying to link evidence to the claim, which I didn't think was strong, but I felt it was much stronger at that presentation, than it was up to that presentation. Because before they'd give me a claim and they'd give me evidence and they'd give me a reason, but they weren't necessarily tied together.*

This quote is interesting because it suggests that the students were including evidence and reasoning to support their claims during their presentations. However, if we look back at the students' arguments (such as Elena and Jordan's arguments), they provided limited justifications for their claims. Furthermore, in her enactment of the Reading the Argument Lesson she praised students when they had more asterisks on their papers, which they were only supposed to add when they read a piece of scientific evidence. This suggests she had a broad interpretation of what counts as evidence in science. In terms of the goal of using the structure, Ms. Brennan discussed it as supporting the "language of the discipline" rather than connecting the structure to a more global rationale such as supporting the construction and critiquing of knowledge claims.

In terms of argumentation as a process, this idea did not emerge in either interview. This is particularly interesting in the Science Seminar lesson in which the goal was to encourage student-to-student interactions. However, Ms. Brennan interpreted the lesson differently and talked about it as supporting presentation skills, "I think it reinforced guidelines, solid guidelines for presentation, I thought that was awesome, I feel that it gave them the opportunity specifically with argumentation, to use the language of the discipline and to follow the sequence." Her understanding of the structural goals was focused more on terms, suggesting a more algorithmic interpretation, and the dialogic goals instead focused on presentation.

As a curriculum user, Ms. Brennan attempted to closely follow the curriculum. The language Ms. Brennan used during the lessons often came verbatim from the curriculum. During both interviews, she talked about how she appreciated the structure of the curriculum

and being able to follow it, including being able to read text directly from the curriculum. For example, during the first interview she said, "Yes the teacher's guide. The flow of the teacher's guide the fact that the things we should say directly uhm are, are you know put in that special little speech box." In talking about the Science Seminar, she made a very similar comment:

> *the way that lesson is set up again, I so much appreciate getting that, you know you can practice it, but you can also walk through it and it stays with you, you know even to the point of "say this" in the textbox*

Although Ms. Brennan attempted to follow the curriculum, at times reading directly from it, her enactment differed greatly from the intended goals. This suggests that just reading direct quotes does not necessarily capture the underlying epistemic goals of the argumentation lessons or enable teachers to develop a classroom culture of argumentation.

In addition, Ms. Brennan's enactment may have been influenced by her prior experiences using teacher-centered instruction. For example, in the interview after the Science Seminar lesson, she talked about how the structure of the lessons was very different from how she typically structures her classroom. For example, she said:

> *I usually, usually, usually I have them, depending on the class and what we're doing, there's floor outlets for example, so if we're using anything with electricity, the configuration changes, but usually, they are more geared toward people all facing the front of the room, and you know, which is more like - not like a lecture hall necessarily, but they wouldn't necessarily be moved for group work.*

Typically, Ms. Brennan structured her classroom so that the students were "all facing the front of the room," which may have also influenced her interpretation of the argumentation lessons. For instance, during the Science Seminar, despite physically having the students sit in two concentric circles, the act of having one student at a time present at the front of the room aligned more closely with her traditional classroom structure. This suggests that Ms. Brennan's prior teaching experiences may have influenced her interpretation of the curriculum. Consequently, although Ms. Brennan talked about following the curriculum and did not appear to believe she had made significant adaptations, her enactment differed significantly from the presentation of argumentation in the curriculum for both structure and as a dialogic process.

DISCUSSION

Across the 10 teachers, we observed a wide range in teachers' enactment of the argumentation lessons. This aligns with previous research showing that teachers enacting the same argumentation curriculum can do so in very different ways (Berland & Reiser, 2011; Herrenkohl & Cornelius, 2013; McNeill, 2009). Specifically, in our study for some instances, teachers' instructional practices supported the underlying epistemic goals of the practice, while in other cases the structural aspects were oversimplified and discourse norms followed traditional teacher-led patterns.

One of the reasons *A Framework for k-12 Science Education* (NRC, 2012) provides for shifting the language in the science standards from scientific inquiry to science practices is that the term inquiry has been used in the science education community in a variety of ways. For example, Lee, Lewis, Adamson, Maerten-Rivera, & Secada (2008) found that teachers perceived "hands on" as scientific inquiry, leaving out the more complex aspects

of sensemaking. The results from this study offer a similar caution for science practices in that instruction identified as focusing on argumentation can include surface level features (e.g., the inclusion of the words claim, evidence, and reasoning), but lack a fundamental "grasp" of scientific practice (Ford, 2012). Berland and Hammer (2012) discuss the idea of "pseudoargumentation" in relation to students' engagement in argumentation, in that students can focus their "attention more on following the instructions and satisfying the teacher than on the substance of the ideas" (p. 72). Our work suggests that pseudoargumentation can also be important to consider in terms of the needs of teachers (McNeill, González-Howard, Katsh-Singer, & Loper, 2016). Teachers' understanding and conceptualizations of an argumentation lesson may focus on surface level features (like specific terms or moving students into a circle), rather than larger epistemic goals of this practice.

To better support teachers in integrating argumentation in their classrooms, we need to develop stronger understandings of *why* they adapt curriculum in particular ways. A stronger understanding of teachers' rationales is critical for designing more effective materials (Davis et al., 2016). Specifically, we found three main curricular decision-making factors in classes with higher quality argumentation: (1) teachers' understanding of argumentation as an epistemic practice, (2) teachers as critically reflective curriculum users, and (3) teachers problematizing their prior teaching experiences.

Teachers' Understanding of Argumentation as an Epistemic Practice

Developing a rich understanding of argumentation can be challenging for teachers (McNeill & Knight, 2013). In this study, teachers' understanding of argumentation varied in terms of the structural and dialogic elements of this practice as well as the underlying rationale for its importance in the classroom. Teachers with higher quality argumentation instruction were more likely to have stronger understandings of argumentation in terms of the larger goals of this epistemic practice. These teachers were able to connect argumentation to being key to scientific sensemaking (Ford, 2012). For teachers with lower quality argumentation instruction, although they discussed argumentation during the post-lesson interviews, their descriptions and explanations focused on surface-level features and lacked a discussion of critique and the social construction of knowledge claims in science. Previous work examining the fidelity of curriculum has often focused on procedural or scripted elements of the curriculum (O'Donnell, 2008). The findings from this research suggests that focusing more on goals and underlying rationales for curricular decisions, such as suggested by Davis and Krajcik (2005), may be more productive for supporting teachers in science practices such as argumentation. We found that following the "script" did not always result in an enactment that supported argumentation as an epistemic practice.

A challenge for future design of educative materials is to help teachers develop a rich understanding of disciplinary practices. The curriculum used by the teachers in this study provided substantial support for teachers around argumentation, including text-based educative notes providing rationale for curricular design choices. However, as shown in the case studies, these materials were not sufficient to support high-quality argumentation instruction by all teachers. One possible explanation is the limits of text-based depictions of argumentation. Alozie et al. argue that "... the complexity of dialogic, inquiry discussions makes them difficult to capture and scaffold in print-based curriculum materials alone" (p. 417, 2010). Consequently, this suggests that providing multimedia images of practice (such as videos) that illustrate and contrast argumentation with other forms of instruction may be a productive avenue to help teachers develop a richer understanding that moves beyond pseudoargumentation. Multimedia cases grounded in real-life situations can support teacher learning by offering a rich and multilayered image of classroom teaching (van den

Berg, Wallace, & Pedretti, 2008). Linking video cases specifically to a teacher's curriculum can help support the development of pedagogical content knowledge as the educative supports are situated in their own practice (Roth et al., 2011). Specifically, the results of our study suggest the importance of illustrating the dialogic aspects of argumentation. For example, juxtaposing two video clips from Ms. Norman's Science Seminar, one in which the students are directly talking to each other compared to another where Ms. Norman was leading the discussion in a traditional teacher *initiate*, student *respond*, and teacher *evaluate* interaction pattern (Mehan, 1979), could help teachers develop a stronger understanding of argumentation as a dialogic process, compared to print-based curriculum. This type of video use may support teachers, such as Ms. Brennan, realize that students should be debating ideas with one another during a seminar, and not presenting individual arguments to the class.

Teachers as Curriculum Users: Supporting Critical Reflection

This study also suggests that teachers who discussed trying to closely follow the curriculum, like Ms. Brennan, had lower quality argumentation instruction. Although these teachers did read text verbatim and followed the instructional sequence, they made changes to the lessons that diminished the epistemic function of argumentation and decreased the focus on the dialogic process. Zohar (2008) argues that when teachers use instructional materials based on reform-oriented ideas that they are not familiar with, they can end up paying attention to superficial aspects rather than the core ideas. Consequently, we argue that it is more important to support teachers in developing deeper understandings of the underlying goals of the curriculum, rather than to support them in following the steps or specific script in a lesson.

We also found that some of the stronger argumentation instruction came from teachers who were more reflective curriculum enactors, thoughtfully making connections to similar experiences with their students and trying to learn from the materials about argumentation. Previous research focused on student learning suggests that online environments that support individuals' reflection result in stronger learning outcomes (U.S. Department of Education, 2009); however, more work needs to focus on the role of reflection in teacher learning. One limitation of this study is that this version of the curriculum did not include supports for teacher reflection. Rather, those teachers who were more reflective in their *use* exhibited stronger argumentation instruction. Future research should examine curriculum that provides more explicit support for teachers as reflective curriculum users.

Previously, we mentioned utilizing video with images of practice within a curriculum to potentially help teachers' understanding of scientific argumentation. In addition, it could be important to layer on top of those images opportunities for teacher reflection. We can envision this occurring in multiple ways. For example, we discussed previously juxtaposing two different video clips to illustrate dialogic interactions in Ms. Norman's class. These types of images could also include footage of teachers reflecting on their practice to illustrate the importance of these behaviors to support instructional change. For example, the videos could include commentary from Ms. Norman like, "I wanted them to have the discussion amongst themselves and so I have to think about how I do that with the other classes. So that I don't- I don't want to be who they're directing this to I want them to be talking to each other more." A multimedia environment could potentially offer more dynamic models of this type of reflection in contrast to traditional paper based curricula that provide a static representation of concepts and activities.

Teachers' Prior Teaching Experiences: Problematizing Instruction

Cohen (1990) argues that teachers make sense of new reform efforts by drawing from their previous teaching experiences. This results in hybrid instruction that mixes together the old and the new. In this study, we found that teachers' prior teaching experiences played a role in their curricular decision making and were related to the quality of their argumentation instruction. The teachers with lower quality argumentation instruction were more likely to discuss prior teacher-centered instruction, which conflicted with the dialogic argumentation learning goals. Furthermore, some teachers, like Ms. Brennan, did not appear to see a difference between their more traditional views on teaching compared to those in the curriculum. This is an important consideration for the design of curriculum to support scientific argumentation, particularly in terms of the dialogic aspects such as critique, since these elements can differ from previous science instruction.

This suggests the importance of problematizing teacher learning about disciplinary practices. Reiser (2004) discusses the concept of problematizing in relation to scaffolding student learning to "... help students see something as requiring attention and decision making that they might otherwise overlook" (p. 287). Similarly, teachers could also benefit from having certain aspects of the curriculum, especially areas that introduce new or unfamiliar practices, stand out to them so that they give those areas more attention. Furthermore, curriculum may need to highlight or help teachers notice features of their previous instruction, which they were not previously aware of. Future research should explore how educative materials can problematize teacher practice to create a sense of dissonance. For example, teachers, such as Ms. Brennan, need to see how these learning goals are different from their previous instruction. One potential avenue for such support could be to customize the educative curriculum for individual teachers' needs based on their responses to questions about their own prior teaching experiences.

Limitations and Future Work

As a field, we need to think critically about how to design teacher education experiences to discourage the relabeling of traditional classroom instruction with reform-oriented practices, such as scientific argumentation, and instead support transformation in classroom instruction. Educative curriculum materials provide a potential avenue for supporting teacher learning around disciplinary practices (Davis & Krajcik, 2005). However, the design of such materials needs to consider teachers' curricular decision-making around enactment (Davis et al., 2016). Specifically, our work suggests that for classroom instruction to move beyond pseudoargumentation, teachers may be required to develop a deeper understanding of argumentation as an epistemic practice, become critical and reflective curriculum users, and problematize their prior teaching experiences.

Because of the small sample size and comparative case study approach used in this work, we cannot make causal claims or generalize these findings to all teachers. The teachers who participated in this study were all interested in enacting a reform-oriented curriculum. Consequently, they could have different views or practices compared to a larger sample of teachers. Future research needs to further explore these potential factors with a larger and more representative group of teachers to determine whether or not these patterns are consistent outside of these 10 teachers. In addition, more research is needed to investigate how to tailor educative curricula to these specific needs. Future research examining text-based curriculum should investigate how to support teachers in moving beyond a script to develop deep understandings of the underlying learning goals, such as argumentation. In addition, future research should examine how multimedia environments can be used to

provide multilayered images of classroom practice, support critical reflection, and customize examples to create dissonance. We need to take advantage of recent technological advances to design new multimedia educative curriculum materials and digital learning environments for teachers around science practices, like argumentation.

As a field, we need to consider *how* and *why* teachers are using different curricular tools as they make important instructional decisions for their classroom needs. We need to think critically about how to design teacher education experiences to discourage the relabeling of teaching with reform-oriented terms, such as argumentation, and instead support instructional transformation.

This research was conducted as part of the Constructing and Critiquing Arguments in Middle School Science Classrooms: Supporting Teachers with Multimedia Educative Curriculum Materials project, supported in part by the National Science Foundation grant DRL-1119584. The design of the earth science curriculum was funded in part by a grant from the Bill & Melinda Gates Foundation. Any opinions expressed in this work are those of the authors and do not necessarily represent either those of the funding agencies, Boston College, Lawrence Hall of Science or the University of Berkeley. We would like to thank Jeremy Price for his feedback on this work as well as Daniel Pimentel and Kimia Mavon for their assistance with data analysis.

REFERENCES

Alozie, N. M., Moje, E. B., & Krajcik, J. S. (2010). An analysis of the supports and constraints for scientific discussion in high school project-based science. Science Education, 94, 395–427.

Arias, A. M., Bismark, A. S., Davis, E. A., & Palincsar, A. S. (2016). Interacting with a suite of educative features: Elementary science teachers' use of educative curriculum materials. Journal of Research in Science Teaching, 53(3), 422–449.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is—or might be—the role of curriculum materials in teacher learning and instructional reform? Educational Researcher, 25(9), 6–8.

Banilower, E. R., Smith, P. S., Weiss, I. R. Malzahn, K., A., Campbell, K. M., & Weis, A. M. (2013). Report of the 2012 national survey of science and mathematics education (pp. 1–309). Chapel Hill, NC: Horizon Research Inc.

Berland, L. K. (2011). Explaining variations in how classroom communities adapt the practice of scientific argumentation. Journal of the Learning Sciences, 20, 625–664.

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

Berland, L. K., & Reiser, B. J. (2011). Classroom communities' adaptations of the practice of scientific argumentation. Science Education, 95, 191–216.

Beyer, C., Delgado, C., Davis, E., & Krajcik, J. (2009). Investigating teacher learning supports in high school biology curricular programs to inform the design of educative curriculum materials. Journal of Research in Science Teaching, 46(9), 977–998.

Brown, M. W. (2009). The teacher-tool relationship: Theorizing the design and use of curriculum materials. In J. Remillard, B. Herbel-Sisenham, & G. Lloyd (Eds.), Mathematics teachers at work: Connecting curriculum materials and classroom instruction (pp. 17–37). New York, NY: Routledge.

Bryan, L. A. (2012). Research on science teacher beliefs. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), Second international handbook of science education (Vol. 1, pp. 477–495). Dordrecht, The Netherlands: Springer.

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.

Cervetti, G. N., Barber, J., Dorph, R., Pearson, P. D., & Goldschmidt, P. G. (2012). Impact of an integrated approach to science and literacy in elementary school classrooms. Journal of Research in Science Teaching, 49(5), 631–658.

Cohen, D. (1990). A revolution in one classroom: The case of Mrs. Oublier. Educational Evaluation and Policy Analysis, 12(3), 311–329.

Crippen, K. J. (2012). Argument as professional development: Impacting teacher knowledge and beliefs about science. Journal of Science Teacher Education, 23(8), 847–866.

Davis, E. A., Beyer, C., Forbes, C. T., & Stevens, S. (2011). Understanding pedagogical design capacity through teachers' narratives. Teaching and Teacher Education, 27, 797–810.
Davis, E. A., Janssen, F. J. J. M., & Van Driel, J. H. (2016). Teachers and science curriculum materials: Where we are and where we need to go. Studies in Science Education, 52(2), 127–160.
Davis, E. A., & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. Educational Researcher, 34(3), 3–14.
Debarger, A. H., Penuel, W. R., Moorthy, S., Beauvineau, Y., Kennedy, C. A., & Boscardin, C. K. (2017). Investigating purposeful science curriculum adaptation as a strategy to improve teaching and learning. Science Education, 101(1), 66–98.
Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. Science Education, 84, 287–312.
Duschl, R. A. (2008). Quality argumentation and epistemic criteria. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), Argumentation in science education: Perspectives from classroom-based research (pp. 159–175). Dordrecht, The Netherlands: Springer.
Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), Handbook of research on teaching (pp. 119–161). New York, NY: Macmillan.
Evagorou, M., & Dillon, J. (2011). Argumentation in the teaching of science. In D. Corrigan, J. Dillon, & R. Gunstone (Eds.), The professional knowledge base of science teaching (pp. 189–204). New York, NY: Springer.
Ford, M. J. (2012). A dialogic account of sense-making in scientific argumentation and reasoning. Cognition and Instruction, 30(3), 207–245.
Hakuta, K., & Santos, M. (2013). Challenges and opportunities for language learning in the context of the CCSS and the NGSS. Journal of Adolescent & Adult Literacy, 56(6), 451–454.
Herrenkohl, L. R., & Cornelius, L. (2013). Investigating elementary students' scientific and historical argumentation. Journal of the Learning Sciences, 22, 413–461.
Jiménez-Aleixandre, M. P., & Erduran, S. (2008). Argumentation in science education: An overview. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), Argumentation in science education: Perspectives from classroom-based research (pp. 3–28). Dordrecht, The Netherlands: Springer.
Katsh-Singer, R., McNeill, K. L., & Loper, S. (2016). Scientific argumentation for all? Comparing teacher beliefs about argumentation in high, mid and low SES schools. Science Education, 100(3), 410–436.
Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the Next Generation Science Standards. Journal of Science Teacher Education, 25, 157–175.
Kuhn, D., Black, J., Keselman, A., & Kaplan, D. (2000). The development of cognitive skills to support inquiry. Cognition and Instruction, 18(4), 495–523.
Lee, O., Lewis, S., Adamson, K., Maerten-Rivera, J., & Secada, W. G. (2008). Urban elementary school teachers' knowledge and practices in teaching science to English language learners. Science Education, 92, 733–758.
Marshall, C., & Rossman, G. B. (1999). Designing qualitative research (3rd ed.). Thousand Oaks, CA: Sage.
McNeill, K. L. (2009). Teachers' use of curriculum to support students in writing scientific arguments to explain phenomena. Science Education, 93(2), 233–268.
McNeill, K. L., González-Howard, M., Katsh-Singer, R., & Loper, S. (2016). Pedagogical content knowledge of argumentation: Using classroom contexts to assess high quality PCK rather than pseudoargumentation. Journal of Research in Science Teaching, 53(2), 261–290.
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.
McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. Journal of the Learning Sciences, 15(2), 153–191.
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.
McNeill, K. L., Pimentel, D. S., & Strauss, E. G. (2013). The impact of high school science teachers' beliefs, curricular enactments, and experience on student learning during an inquiry-based urban ecology curriculum. International Journal of Science Education, 35(15), 2608–2644.
Mehan, H. (1979). Learning lessons: Social organization in the classroom. Cambridge, MA: Harvard University Press.
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.
Miles, M., & Huberman, A. M. (1994). Qualitative data analysis: An expanded sourcebook (2nd ed.). Thousand Oaks, CA: Sage.
National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: National Academy Press.

NGSS Lead States. (2013). Next generation science standards: For states, by states. Washington, DC: National Academies Press.

O'Donnell, C. L. (2008). Defining, conceptualizing, and measuring fidelity of implementation and its relationship to outcomes in K-12 curriculum intervention research. Review of Educational Research, 78(1), 33–84.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. Science, 328, 463–466.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. Journal of Research in Science Teaching, 41(10), 994–1020.

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. Journal of the Learning Sciences, 13(3), 423–451.

Pearson, P. D., Moje, E., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other. Science, 328, 459–463.

Polman, J. L. (2004). Dialogic activity structures for project-based learning environments. Cognition and Instruction, 22(4), 431–466.

Powell, J. C., & Anderson, R. D. (2002). Changing teachers' practice: Curriculum materials and science education reform in the USA. Studies in Science Education, 37, 107–136.

Putnam, R., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? Educational Researcher, 29(1), 4–15.

Quintana, C., Reiser, B., Davis, E. A., Krajcik, J., Fretz, E., Golan, R., Kyza, E., … Soloway, E. (2004). A scaffolding design framework for designing educational software. Journal of the Learning Sciences, 13(3), 337–386.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. Journal of the Learning Sciences, 13(3), 273–304.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. Review of Educational Research, 75(2), 211–246.

Roth, K., & Garnier, H. (2006). What science teaching looks like: An international perspective. Educational Leadership, 64(4), 16–23.

Roth, K. J., Garnier, H. E., Chen, C., Lemmens, M., Schwille, K., & Wickler, N. I. Z. (2011). Videobased lesson analysis: Effective science PD for teacher and student learning. Journal of Research in Science Teaching, 48(2), 117–148.

Roychoudhury, A., & Rice, D. (2010). Discourse of making sense of data: Implications for elementary teachers' science education. Journal of Science Teacher Education, 21, 181–203.

Sadler, T. D. (2006). Promoting discourse and argumentation in science teacher education. Journal of Science Teacher Education, 17, 323–346.

Sampson, V., & Blanchard, M. R. (2012). Science teachers and scientific argumentation: Trends in view and practice. Journal of Research in Science Teaching, 49(9), 112–1148.

Sampson, V., & Clark, D. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. Science Education, 92, 447–472.

Sandoval, W. A., & Cam, A. (2011). Elementary children's judgment of the epistemic status of sources of justification. Science Education, 95, 383–408.

Schneider, R. M. (2013). Opportunities for teacher learning during enactment of inquiry science curriculum materials: Exploring the potential for teacher educative materials. Journal of Science Teacher Education, 24, 323–346.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., Fortus, D., … Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. Journal of Research in Science Teaching, 46, 632–654.

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.

Stake, R. E. (2000). Case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), Handbook of qualitative research. Thousand Oaks, CA: Sage.

Tabak, I. (2004). Synergy: A complement to emerging patterns in distributed scaffolding. Journal of the Learning Sciences, 13(3), 305–335.

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

U.S. Department of Education. (2009). Evaluation of evidence-based practices in online learning: A meta-analysis and review of online learning studies. Washington, DC: Author. Retrieved from www.ed.gov/about/offices/list/opepd/ppss/reports.html.

van den Berg, E., Wallace, J., & Pedretti, E. (2008). Multimedia cases, teacher education and teacher learning. In J. Voogt & G. Knezek (Eds.), International handbook of information technology in primary and secondary education (pp. 475–487). New York, NY: Springer.

Viennot, L., Chauvet, F., Colin, P., & Rebmann, G. (2005). Designing strategies and tools for teacher training: The role of critical details, examples in optics. Science Education, 89, 13–27.

Zohar, A. (2008). Science teacher education and professional development in argumentation. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), Argumentation in science education: Perspectives from classroom-based research (pp. 245–268). Dordrecht, The Netherlands: Springer.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. Journal of Research in Science Teaching, 39(1), 35–62.