Beginning Elementary Teachers' Beliefs About the Use of Anchoring Questions in Science: A Longitudinal Study

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ABSTRACT: Current science education reform efforts highlight the importance of engaging students in scientifically oriented questions as a central dimension of inquiry-based elementary science. However, elementary teachers, particularly beginning teachers, must often overcome a variety of challenges to engage their students in reform-minded, standards-based, inquiry-oriented classroom practice. To better support beginning elementary teachers' learning to support students to ask and answer scientifically oriented questions, it is necessary to better understand their beliefs about questions and questioning, as well

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as how they negotiate these beliefs at this crucial stage of the teacher professional continuum. Four beginning elementary teachers were studied longitudinally over their first 3 years of professional teaching careers. Results show that each teacher cited the importance of driving questions and investigation questions to establish purpose and promote student sense-making. However, they followed different trajectories in reconciling their ideas about the use of driving questions and investigation questions in light of the particular facets of science teaching they prioritized. These findings have important implications for current perspectives on teacher learning along the teacher professional continuum and help inform research on teachers and teaching, as well as teacher education and science curriculum development. *Sci Ed* **94:**365–387, 2010

INTRODUCTION

Questioning is a critical practice that lies at the heart of teaching. The use of questions and questioning is prioritized in current science education reform, which emphasizes standards-based, inquiry-based science teaching and learning (Krajcik, Blumenfeld, Marx, & Soloway, 2000; National Research Council [NRC], 1996, 2000). Scientifically oriented questions and related questioning practices are fundamental to inquiry-oriented science teaching and learning in which they are highlighted as one of the five essential components of scientific inquiry (NRC, 2000). Such questions are explanatory in nature, focusing on "how" and "why" rather than description and provide an impetus for scientific investigations through which students can collect and organize data, make evidence-based explanations, and communicate their findings and explanations.

Teachers play a crucial role in translating reform-based science, including the use of scientifically oriented questions and questioning, into actual classroom practice. However, teachers themselves espouse particular beliefs about professional practice, including inquiry-based teaching and learning, that are important components of their expertise (Magnusson, Krajcik, & Borko, 1999). These beliefs serve as tools which teachers employ to engage in professional practice and, though direct, causal links between teachers' espoused beliefs and their science teaching practice are not always clear; there is empirical evidence of important relationships between the two (e.g., Fishman, Marx, Best, & Tal, 2003; Lotter, Harwood, & Bonner, 2007; Roehrig, Kruse, & Kern, 2007). Unfortunately, teachers' beliefs are sometimes inconsistent with tenets of effective science teaching and learning advocated by science education reform. Even when teachers' espoused beliefs about science teaching are aligned with those promoted in science education reform, teachers may still face obstacles to actually translating them into practice. Better understanding teachers' beliefs about engaging students in scientifically oriented questions and questioning within inquiry-oriented science learning environments, as well as how they evolve over time, is an important first step in understanding how teachers actually mobilize these beliefs in science teaching practice.

The purpose of this study is to learn more about beginning elementary teachers' beliefs about the use of anchoring questions, one specific type of scientifically oriented question, and how these views develop during the induction phase of their professional teaching careers. Beginning teachers have needs that are unique from those of preservice and experienced teachers and require specialized forms of support (Luft, 2007), particularly given the high attrition rate for teachers in their first few years of teaching (U.S. Department of Education, 2007). Longitudinal research focused on the development of early-career teachers' beliefs is needed to describe the development of their beliefs during this critical phase of their professional careers (Davis, Petish, & Smithey, 2006; Feiman-Nemser, 2001). In this study, we emphasize one particular facet of teaching science as inquiry, engaging students in scientifically oriented questions, and trace four beginning elementary teachers' beliefs about the use of anchoring questions and how they evolve over the study. Findings from this study yield further insight into how beginning elementary teachers can be supported to effectively use driving questions and investigation questions to teach science as inquiry and are an important contribution to research on teachers' beliefs about inquiry and new teacher learning.

QUESTIONS AND QUESTIONING FOR INQUIRY TEACHING AND LEARNING

A core element of teaching and learning involves relating experiences over varying timescales through discourse and the production of artifacts. As Tabak (2004) notes, "students and teachers negotiate what is meaningful and significant by relating to ideas from previous events and by projecting to future events" (p. 328). To make these temporal connections, students need to learn to use language as a tool through which to engage in sense-making about the world. Questions are an important element, if not the foundational element, of classroom discourse aimed at the social construction of meaning (Vygotsky, 1978). They serve to link present activity with past and perceived future activity by explicating the contradictions that drive learning, help define the zone of proximal development, and bridge the gap between socially accepted knowledge and that which remains tentative. While such discourse is often associated with students at advanced stages of development, elementary students can also learn to engage in complex and substantive forms of discourse in science (Gallas, 1995; Metz, 2008; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001; Wells & Arauz, 2006).

Teacher–student discursive interactions, which involve the use of questions, follow semi-consistent patterns that are dependent, in part, on the types and purposes of questions used. These discursive patterns serve as cultural tools that are inexorably tied to the nature of classroom activity (Kelly & Crawford, 1997; Lemke, 1990; Polman, 2004; van Zee & Minstrell, 1997; Wells & Arauz, 2006). Questioning is often the first step, for example, in more traditional patterns of classroom discourse exemplified by initiation–reply–evaluation (I-R-E) or question–answer–evaluation (Q-A-E) teacher–student interactions. In these types of interactions, the teacher poses a question, elicits a response from a student, and provides evaluative feedback on the answer. Questions used in I-R-E or Q-A-E interactions are often descriptive in nature, tending to be expressed in "what," "where," and "who" form. Often such questions are used to highlight, summarize, confirm, and reinforce students' experiences in terms of accepted scientific knowledge.

Using questions and more teacher-directed forms of questioning to frame classroom experiences within and around the accepted scientific explanations for phenomenon is a practice oriented toward particular outcomes. Teachers can and very often do emphasize these descriptive, confirmatory questions to support students to arrive at predetermined learning goals in an efficient manner given the constraints of their institutional contexts. However, the use of these types of questions, modes of questioning, and the broader discursive patterns in which both are embedded, can also have detrimental impacts on the ways in which teachers and students coarticulate, negotiate, and make sense of scientific phenomena. There is evidence that more teacher-centered classroom questioning, or monologic discourse, can limit students' capacities to contribute to collaborative sense-making and effectively shut-down discussion (Carlsen, 1992; Dillon, 1985; Hogan, Nastasi, & Pressley, 1999; Lemke, 1990; Morrison & Lederman, 2003). Limiting students' abilities to engage in meaningful discourse about natural phenomena ultimately has a negative impact on their learning.

In contrast to more teacher-directed discourse, open-ended, collaborative discourse is an integral characteristic of constructivist, inquiry-based science. The descriptive questions and patterns of questioning inherent to monologic discourse described previously must be used in conjunction with dialogic patterns of classroom discourse in which teachers and students engage in collaborative sense-making through the reciprocal use of language. These dialogic discourse patterns are constituent elements of rich science learning environments and serve to scaffold students' knowledge construction by structuring the task of problem-solving and problematizing subject matter (Kelly & Crawford, 1997; Reiser, 2004; Tabak, 2004; van Zee & Minstrell, 1997; Wells & Arauz, 2006). Student sense-making explanation-construction is linked explicitly to questions that guide their investigations (Geier et al., 2008; Krajcik & Blumenfeld, 2006; Krajcik & Mamlok-Naaman, 2006; Sandoval & Reiser, 2004).

Within inquiry-based learning environments characterized by dialogic discourse, particularly project-based science classrooms (e.g., Krajcik & Blumenfeld, 2006), two important types of scientifically oriented questions are *driving questions* and *investigation questions*. These questions, typically "how"' or "why" questions presented at the beginning of science units or individual lessons, are highly visible tools that serve to structure and guide learning activities over varying lengths of time. Driving questions are used throughout science units to engage and motivate students by presenting them with a problem they perceive as worth investigating (Geier et al., 2008; Krajcik & Blumenfeld, 2006Reiser, 2004). They also support teachers to maintain curricular coherence and promote student learning through explicit ties to standards and learning goals. To be effective, driving questions should address important content, be contextualized and meaningful to students, sustainable over weeks of instruction, and answerable (Krajcik & Mamlok-Naaman, 2006). An important aspect of using driving questions is that they serve as central linchpins of consecutive student experiences and are returned to and highlighted throughout the unit. One way to help students make connections between individual experiences given the overall focus of the unit is to employ investigation questions. Investigation questions are similar to driving questions but are used with individual lessons or investigations, often serving as subquestions to driving questions. We refer to driving questions and investigation questions more generally as anchoring questions.

TEACHERS' BELIEFS AND EXPERTISE FOR INQUIRY

Teachers' beliefs play an important role in how and why they engage in certain types of science teaching practices, including inquiry (Fishman et al., 2003; Lotter et al., 2007; Roehrig et al., 2007). They are often assumed to have a direct influence on teachers' professional practice and, as such, have been the subject of a great deal of educational research over the years (e.g., Nespor, 1987; Pajares, 1992; Richardson, 1996). While teachers' beliefs remain an important focus for ongoing research, operationalizing teachers' beliefs, and distinguishing them from teachers' knowledge, orientations, and identities, presents numerous challenges to researchers (e.g., Crawford, 2007). While it is not our intent to try to resolve these challenges in this paper, it is necessary to articulate a theoretical perspective on the nature of teachers' beliefs as an integral component of their expertise for teaching.

Teachers articulate principled, normative claims about dimensions of their professional practice, which provide a window into their cognition and development. At its core, such a claim is a belief, or a "proposition that is accepted as true by the individual holding the belief" (Richardson, 1996, p. 104). There are strong arguments for the interrelationship between beliefs and knowledge. As Coburn suggests, they are "variations on theme" (2004, p. 585) and share a fundamental form and, most importantly, knowledge claims are ultimately grounded in beliefs. In essence, there can be no knowledge in the absence of belief. What counts as teachers' knowledge versus belief is socially constructed within or across communities, a perspective reinforced situated and sociocultural perspectives on teacher learning (Putnam & Borko, 2000), as well as by the observed discord between formal knowledge and practical knowledge in teaching (e.g., Hiebert, Gallimore, & Stigler, 2002).

Whether labeled beliefs or knowledge, teachers' espoused propositions about teaching and learning are deeply embedded in their experience. Teachers recall past experiences to make claims about present situations, which are articulated in the form of beliefs (Nespor, 1987). As such, teachers' belief systems represent "instrumentalities" (Engeström, 2007) that are both derived from practice (principles used to explain experiences) and employed by teachers as tools in practice (predictive principles used to guide future practice). This interactionist view of teachers' knowledge, beliefs, and orientations is consistent with perspectives on learning that foreground the foundational roles of experience and reification of experiences (Engeström, 1987; Latour, 1999; Wenger, 1998), as well as situated views on teacher learning and practice (Putnam & Borko, 2000). Teachers' instrumentalities, also described holistically as teacher characteristics (Brown, 2009) or views (Crawford, 2007), serve as a fundamental dimension of their *pedagogical design capacity* (Brown, 2009), or ability to employ symbolic tools (knowledge, beliefs, and so on) and physical tools (e.g., curriculum materials) effectively in practice to accomplish particular instructional goals within particular professional contexts. As such, teachers' beliefs serve as a crucial component of their expertise, their ability to effectively engage students in epistemic practices, and their capacity to support student learning.

STUDY RATIONALE

While there remain questions about the causal influence of teachers' beliefs on their practice, there is evidence of significant relationships between the two in science teaching practice (Fishman et al., 2003; Lotter et al., 2007; Roehrig et al., 2007). Articulating views of science teaching consistent with those promoted in current science education reform is an important first step for teachers to learn to engage in inquiry. However, elementary teachers often articulate views of science teaching that emphasize hands-on activities and making science engaging and enjoyable for students rather than epistemic inquiry practices (Abell, Bryan, & Anderson, 1998; Appleton & Kindt, 2002; Howes, 2002). They may also deprioritize teaching science as inquiry in light of other concerns, view inquiry as a linear, lockstep process, and fail to acknowledge the social construction of scientific knowledge (Davis, Petish, & Smithey, 2006). Gaining insights into teachers' espoused beliefs about science teaching can inform teacher education, professional development, and the design of science curriculum materials, each of which plays a crucial role in supporting teacher learning across the teacher professional continuum.

Beginning teachers, in particular, face many challenges in teaching science (Davis, Petish, & Smithey, 2006) and require specialized support during the induction phase of their professional teaching careers. Yet, we know little about the needs of these teachers and how they learn during this critical stage of their professional careers (Luft, 2007). Specifically, there is little research on beginning elementary teachers' views about inquiry teaching and learning that could be leveraged to better support them to engage students in classroom inquiry. Here, we address a gap in the literature by focusing specifically on beginning elementary teachers' views on the role of driving questions and investigation questions as a component of their science teaching. Two research questions served to guide this study: *What are beginning elementary teachers' beliefs about the use of driving questions and investigation questions in inquiry-oriented science teaching*? and *How do their beliefs about the use of driving questions and investigation questions in inquiry-oriented science change over time*?

METHODS

The research presented here involved four beginning elementary teachers studied longitudinally over the first 3 years of their professional teaching careers. These results are part of a larger, ongoing longitudinal study of beginning elementary teachers begun in the fall of 2002. Findings from this research have illustrated beginning elementary teachers' science teaching practice and developing expertise and learning, particularly as related to inquiry-oriented science teaching, as well as their use of science curriculum materials (e.g., Beyer & Davis, 2008; Davis, 2008; Forbes & Davis, in press). The four teachers here were chosen to highlight unique sets of beliefs about questions and questioning in science teaching and because complete data sets were collected for each over the first 3 years of their professional teaching careers. Each was a voluntary participant in the study.

Inquiry-Oriented Curriculum Materials

To help support beginning elementary teachers' science teaching, we have developed a technology-mediated teacher-learning environment called the Curriculum Access System for Elementary Science (CASES; Davis, Smithey, & Petish, 2004). CASES provides inquiry-oriented science curriculum materials that are intended to be educative for new teachers (Davis & Krajcik, 2005) and include additional supports, including an online discussion space and reflective journaling tool. CASES is grounded in design principles that are instantiated in the curriculum materials themselves and a three-part model of scientific inquiry derived from that promoted by the NRC (2000). For example, CASES curriculum materials provide rationales for pedagogical approaches and support teachers in adapting them in ways that reflect their unique teaching contexts. Such features help support beginning teachers by making innovative curriculum materials more flexibly adaptive (Barab & Luehmann, 2003; Fishman & Krajcik, 2003), or inherently accessible to teachers whose unique classroom contexts necessitate modification of existing curriculum materials.

Participants and Overview

The four teachers who participated in this study each graduated from an undergraduate elementary teacher education program at a large Midwestern university. The four-term, cohort-based program is aligned with foundational tenets of teacher education reform and content area standards. During the third semester of the program, each of the teachers took an undergraduate elementary science teaching methods course taught by the second author and other members of the CASES research team. Davis and Smithey (2009) provide a detailed description of the program and elementary science teaching methods course. One central aspect of the course involved supporting the preservice teachers' learning to teach science as inquiry, including engaging students in scientifically oriented questions and questioning, a crucial component of numerous inquiry frameworks (Davis et al., 2004; Krajcik & Blumenfeld, 2006; NRC, 2000). In the course, the preservice teachers were afforded multiple and varied opportunities to critique, adapt, enact anchoring questions, as well as reflect upon their use in the classroom with students.

The summer after completing the teacher education program, each teacher obtained an elementary teaching position for the following year and was invited to participate in a multiyear longitudinal study. These teachers were contacted because, based on CASES team members' relationships with them as students in science methods courses, they appeared likely to be reflective about their science teaching and interested in participating in a project that would provide them with a form of professional development in science teaching. The teachers were given the option of participating in the study to varying degrees; they each chose the most substantial level of participation. This involved teaching at least one CASES unit each year, maintaining a variety of records of science teaching practice, and participating in three annual interviews as described in the section that follows. To better enable their use of CASES and communication with the research group members, each teacher was provided a notebook computer early in the first year but did not receive any additional compensation over the course of the study. In the results that follow, pseudonyms are used for the teachers.

Data Collection

Three forms of data were collected in this study. First, semistructured, audiotaped interviews were carried out with the teachers three times annually for 3 years. These interviews were designed to be approximately 45–60 minutes in length, though they often went substantially longer, and occurred once in the fall, winter, and end of the academic year. Each was administered over the phone by CASES research group members, not the authors. These interview protocols were designed to provide the teachers an opportunity to describe their school settings, articulate their general views on science teaching and use of science curriculum materials, and discuss their learning and development. During each of the interviews, the teachers were asked to describe planning for and enactment of science instruction, critique and suggest modifications for sample science lesson plans, and reflect on hypothetical classroom scenarios.

The additional data sources, reflective journals and daily logs, were embedded features of the CASES online environment that the teachers accessed and completed through the Web site in conjunction with their science teaching. The reflective journaling tool is open ended but provides scaffolds to promote productive reflection on practice. The teachers were asked to complete at least one journal entry each week. They were also asked to regularly complete CASES daily logs for each CASES lesson they taught and were encouraged to complete them for most of their science instructional sequences. These daily lots were composed of multiple choice and forced response items that allowed the teachers to describe lesson-specific content and pedagogy. The teachers varied considerably in how consistently they completed journal and daily log entries.

Data Analysis

Each of the audiotaped interviews was transcribed, and all CASES journal entries and daily log files were transformed into standard text documents. We employed thematic analysis to analyze the qualitative data. Because of their substantial depth and richness, the formal interviews were foundational data sources that served as beginning points for analyses. The remaining data sources primarily served to further illuminate thematic trends we observed in the interviews and, in the absence of observational data, teachers' narrative and categorical descriptions of their science instruction.

Analysis involved an iterative process of data coding, reduction, displaying, and verification of data (Miles & Huberman, 1994). We developed a coding key that was used to code

TABLE 1
Coding Key

Code	Description
Characteristics of questions	
Direct	Confirmatory questions often associated with recall
Open-ended	Questions with no predetermined answer
Student-generated	Questions asked by students
Teacher-generated	Questions asked by teachers
Driving question	Scientifically oriented question intended to frame unit-level instructional sequences
Investigation question	Scientifically oriented questions intended to frame individual lessons or multiday investigations
Interactive questioning	Interactive questions and questioning that are used in the moment as part of classroom discourse
Purpose of questions for scientific inquiry	
Questioning and predicting	Questions designed to engage students in scientifically-oriented questions and predicting
Data and evidence	Questions designed to support students' collection, organization, and analysis of data and evidence
Constructing explanations	Questions designed to support students' construction of evidence-based explanations
Connecting explanations	Questions designed to support students' evaluation and comparison of explanations
Communicating and justifying	Questions designed to support students' communication and justification of explanations
Purpose of questions for classroom teaching	
Assessment	Questions designed to assess students' understanding
Connections to real life	Questions designed to support students' linking of classroom science to out-of-school experiences
Curricular coherence	Questions designed to conceptually and organizationally link consecutive learning experiences
Motivating students	Questions designed to motivate students to engage in science
Students' ideas	Questions designed to elicit and clarify students' ideas
Students on-task	Questions designed to facilitate classroom management and focus students on task at hand

all data used in this study. This coding key was informed by existing analytical frameworks for questions and questioning used in previous research (i.e., Koufetta-Menicou & Scaife, 2000; Morrison & Lederman, 2003), as well as the NRC's (2000) five-part framework for classroom inquiry practices. These codes were designed to characterize the teachers' espoused beliefs within two domains: characteristics of questions, particularly anchoring questions, and the purpose(s) for engaging students in questioning, both as part of inquiry and general classroom practice. Additional codes were added to account for emergent themes related to these dominant categories. Our final coding key is presented in Table 1.

As definitive patterns emerged, the data were reduced to isolate and illustrate key factors. We used the codes for types of questions from Table 1 to differentiate between the teachers' beliefs about investigation questions, driving questions, and other types of questions. In coding for the teachers' purposes for the use of questions in their science teaching, we coded for their relationships to assessment, motivating students and keeping them on-task, accounting for students' ideas, and establishing connections across lessons and with life outside of school. The dominant theme across these categories revolved around making the purpose of lessons and investigations explicit for students. In coding for the teachers' purposes for the use of questions specifically for inquiry, we coded for five essential features of inquiry (NRC, 2000). The dominant theme across these categories revolved around promoting students' sense-making about scientific phenomena. Data analysis continued until dominant themes had been refined and substantiated. Two primary themes were found for the elementary teachers' beliefs about the use of questions and questioning: to make the purposes of investigations explicit to students and to promote student sense-making, which are discussed in the Results section.

To enhance the validity of conclusions, we triangulated data between the interviews, reflective journals, and daily logs. The purpose of this was to challenge tentative claims generated from the interview data by searching for supporting and contrasting data and, through disparate data, further elaborate the phenomena under study. Second, we sought to achieve a high level of interrater reliability. The first author coded 100% of the data. A second independent rater coded a subset of the data that was selected at random. The average interrater reliability was 85%. After discussion, 100% agreement was reached.

RESULTS

The findings presented here illustrate how these four beginning elementary teachers—Lisa, Catie, Whitney, and Brooke—each expressed unique ideas about the role of questions and questioning in inquiry-oriented science. First, each of the teachers prioritized the use of anchoring questions to promote student sense-making and to make the purpose of science learning opportunities explicit to students. Second, their beliefs about the use of anchoring questions evolved alongside other goals and beliefs they held about effective science teaching and learning. Finally, they articulated perceived challenges in their professional contexts to their desired use of anchoring questions in science teaching practice.

Teacher Cases

Lisa. Of the four teachers, Lisa's talk about the purposes of using anchoring questions in of her science teaching was the most consistent. Throughout the study, Lisa prioritized the use of these questions as a means through which to make the purpose of learning experiences explicit to students and to promote student sense-making. This trend appeared to be influenced by Lisa's experiences teaching science in her first year. Lisa noted challenges she perceived in promoting student learning early in her first year, writing, "I would ask students 'what did you learn from the lab?' and some students were unable to articulate a single idea" (Lisa, Year 1 Journal, 10–12).[1] In this same journal entry, she reflected on how she wanted to subsequently move forward with her science teaching, writing,

> I need to make sure that students know what they were supposed to learn by doing the experiment. I think I have been too focused on having the kids explore and develop meaning for themselves that I do not specifically tell them what they were supposed to learn from that lesson. . . I can tell myself that it is okay if I tell them that this is what they were supposed to learn and I do not have to be so ambiguous with them. I worried that

[1] Quotes from participant journal entries are labeled name [pseudonym], Year [year] Journal, [line number(s) from document]

> specifically telling them "this is how it is" would take away from their discovery, but I feel the way I give them hands-on experiments I can still explicitly teach them while they implicitly connect and reconnect the correct concepts. (Lisa, Year 1 Journal, 12–37)

It is apparent from Lisa's very early enactment experiences that she wrestled with how much guidance to provide students as a part of science instruction. From this point on, Lisa began to emphasize less student-directed beliefs about science teaching that involved making goals for learning explicit to students.

Lisa's emphasis on explicating learning goals in her science teaching was evident in her developing beliefs about the use of anchoring questions. She noted that these questions could help her "keep the kids focused" and that she "like[d] having a question to always focus the kids on" (Lisa, Int. 1.3, 556–560).[2] Here, Lisa's emphasis on using driving questions and investigation questions as an anchor-point for instruction is clear. Even by the end of her first year, Lisa consistently articulated a need to use questions in science (Lisa, Year 1 Daily Logs 1, 2, 3, 5, and 7).[3] The use of questions and questioning had become a fundamental part of Lisa's view of effective science teaching. For example, she said,

> . . . effective science teaching would be presenting a question to a kid that is feasibly able to search out and discover. Once you have this question, or problem, or topic in a question [form] . . . that'd be the base of the whole science unit. Good science teaching is . . . giving the kids the questions, . . . building up their anticipation to answer the questions. (Lisa, Int. 1.3, 393–397)

Lisa's emphasis on the use of questions as an important dimension of effective science teaching remained consistent throughout the study.

Lisa not only prioritized questions as a way to orient students to the purpose of individual activities but also began to emphasize questions that would lead students to construct explanations about scientific phenomena. Toward the end of her first year, Lisa described what she perceived to be an overemphasis in her science curriculum on factual knowledge, saying, "a lot of times in my curriculum, they only want you to know 'this' and 'this"' (Lisa, Int. 1.3, 512). She noted she often felt that she could "really make a good higher or more in-depth type of question to go along with it" (Lisa, Int. 1.3, 556–559). Lisa's emphasis on prioritizing these questions was evidenced in her critique of a fictional science teaching scenario where she was critical of the investigation used by the teacher. Lisa said,

> It says "what are all the possible ways to light the bulb using just the wire and the batteries?." I don't like that question because all is it is looking for an outcome. It doesn't get the kids to think about the ways that didn't work, and why they didn't work, and the whole purpose of a hands on activity is having the kids try things out to learn . . . All they're going to be thinking about are all the possible ways, and once they get one way, they're going to try another way without thinking why this worked. (Lisa, Int. 2.1, 1126–1134)

In this example, Lisa's two primary justifications for using investigation questions—making the purpose explicit to students and promoting student sense-making—interact in her critique of this scenario. Because the investigation question sets students' goals, it is important

[2] Quotes from participant interviews are labeled as name [pseudonym], Int. [year.interview #], [line number(s) from transcribed document]

[3] Quotes from participant daily logs are labeled as name [pseudonym], Year [year] Daily Log, [daily log number(s)]

for the question to be explanatory in nature since Lisa's goal was to promote student sense-making.

In her second and third year, Lisa continued to emphasize anchoring questions, saying, "the whole point of a lesson is centered around the question" (Lisa, Int. 3.2, 625–626). She also noted that she was satisfied with her use of driving questions and investigation questions as part of her science teaching, saying,

> I like the way I question the kids. I'm getting the kids to answer my questions freely and I keep them really open-ended so I'm never there giving them "oh yep, you're right. Nope, you're wrong." So I kind of just keep questioning, questioning, questioning, and then I might just stop and then the next day we'll talk about it or we'll do a lab to figure out those questions. So I like the way I use questions. I have the kids questions themselves or each other or what are they going to do. Why did this work? I don't think I would change any of that. (Lisa, Int. 2.1, 510–516)

When asked how she hoped to be teaching science in 5 years, this emphasis on questions and questioning continued each year. She noted that she would "probably be doing the same thing . . . having a unit question" because she felt that students need to have a sense of "direction or what's the point of learning" and "some guiding light [to keep] them focused throughout the whole unit" (Lisa, Int. 2.1, 458–461). She also reiterated the importance of promoting student sense-making through questioning, saying "you don't want them to be able to answer it in one sentence or by doing one thing . . . you have to get them to like think beyond . . . it's not just 'what color is a rose?,' you've got to ask 'why is a rose a shade of red?"' (Lisa, Int. 3.2, 602–605). These findings illustrate how Lisa intended to continue emphasize the use of anchoring questions to explicate purpose and promote student sense-making.

In sum, Lisa's beliefs about the use of driving questions and investigation questions remained relatively stable over the course of the study. Early in her first year, Lisa began to emphasize the important role anchoring questions can serve in making explicit shared purposes of science learning experiences and as a sense-making tool. After initially articulating these beliefs, Lisa consistently reinforced them over the course of the study and reported a high degree of confidence in her ability to engage her students in inquiry-based questioning practices. However, Lisa's case was the exception. Unlike Lisa, the other three teachers' beliefs about the use of driving questions and investigation questions evolved over the course of the study. We turn next to those cases.

Catie. Like Lisa, Catie began her first year of teaching with a set of experiences that influenced her beliefs about anchoring questions. In the first year of the study, Catie developed a water quality unit centered around pollution in a local lake and said that including investigation questions helped, "focus me so when I was looking for things that I needed in order to teach this unit I was able to say, 'here's what I want them to know"' (Catie, Int. 1.1, 469). After teaching the unit, she noted that she believed these questions helped her students gather existing information and evidence that they would use throughout the unit, saying, "when we did the discussion I had tons of stuff under each question . . . I was completely amazed that they were able to find so much stuff when they hadn't before" (Catie, Int. 1.1, 468–470). This experience reinforced the growing importance that Catie placed on anchoring questions. Afterward, she said "I think questions are very important . . . so students can focus" (Catie, Int. 1.1, 436).

As time went on, Catie continued to discuss the importance of anchoring questions to provide a sense of purpose and promote student sense-making. She emphasized how "students need questions to guide their thinking during the tasks" (Catie, Year 1 Journal, 31) and, in discussing an interview scenario in her second year, highlighted the importance of using questions that required students to justify the claims that they make, saying,

> I think that that question not only allows for them to think about how they're going to do it but also how to later on explain how they did. Asking them a question so that they think about why they chose it I think is important. (Catie, Int. 2.3, 1298–1300)

Despite the importance she placed on anchoring questions in science, she noted challenges she perceived in developing these questions when they were not included in science curriculum materials she used. Although she reported developing driving questions for her water quality unit, she discussed challenges she perceived doing so with other science units. For example, she recalled a unit on flight taught later in her first year, noting how difficult it would have been to develop anchoring questions

> because of the [curriculum] materials I had ... it was kind of just taking little bits and pieces of activities and things and putting them together so that they would learn these four learning goals ... there weren't really any questions behind them. (Catie, Int. 1.3, 174–176)

Not surprisingly, she expressed much more confidence in using anchoring questions when they were included in curriculum materials, including CASES curriculum materials, saying, "there are more questions to ask them that are right there that I don't have to think of—that's really great" (Catie, Int. 1.2, 370–372).

As Catie transitioned into her new position as a second-grade teacher in her second year, her beliefs about the use of anchoring questions began to evolve. As she noted, "I really try and stay with what the other teachers are doing and just incorporate whatever is in the CASES unit into what I'm doing" (Catie, Int. 2.2, 458–460). Catie began to express a concern about students being too eager to answer these questions before engaging in investigations to address them. She believed that students with more prior knowledge about scientific phenomena would influence other students' opportunities to engage in inquiry to address specific driving questions and investigation questions. She suggested that some students "give away all the answers" and, as a result, other students "hook onto those ideas ... it's like they're a clean slate up until you ask the question and then ... they're holding onto [those ideas] because someone else said it" (Catie, Int. 3.3, 1303–1307). She mentioned that in her own experience, "sometimes if we do something and then ask the questions then I get a better answer from the kids who aren't so knowledgeable about everything" (Catie, Int. 3.3, 1308–1309).

In her discussions of the interview scenarios, this issue seemed to weigh heavily on her thinking about using driving questions and investigation questions. She still emphasized the use of questions to scaffold students' sense-making and talking, mentioning the importance of "why" questions and addressing investigation questions "at the beginning and the end of the lesson" (Catie, Int. 2.3, 1339). However, her concern about some students "giving away the answers" influenced how she talked about introducing investigation questions. She noted, for example, in reference to a scenario involving students in designing waterproof coverings for sponges, that she would "probably present [the question] at the beginning but not talk about it" (Catie, Int. 2.3, 1319). She was concerned that "if you start talking about it beforehand then some kids who are more knowledgeable about the topic are going to start giving the ideas and then you'll get a bunch of sponges that are packaged the same way" (Catie, Int. 2.3, 1322). To give all students an opportunity to engage in authentic inquiry to address the investigation question, Catie suggested the investigation question be "presented first and kind of left it there" and then, after students had performed the investigation, "talk about how they did it, why they did it a certain way, stuff like that" (Catie, Int. 2.3, 1333).

In sum, Catie consistently expressed beliefs about the importance of anchoring questions in science to promote student sense-making and established a sense of purpose. However, she wrestled with concerns that some students would attempt to provide quick answers to questions meant to guide learning experiences. As such, over time, Catie began to emphasize the importance of returning to investigation questions only after instruction and not as tools of eliciting students' initial ideas and explanations. She also described important features of her science curriculum materials and professional context that she perceived as constraints to her use of anchoring questions. At the end of the study, Catie continued to wrestle with how to use anchoring questions in ways that were motivating and engaging for her students.

Whitney. Like Catie and Lisa, Whitney prioritized the use of driving questions and investigation questions to go beyond description and recall and to promote student sense-making about scientific phenomena, as well as to make the purpose of science learning opportunities explicit. She noted early in her first year that she thought "it's good to start with a question because you're engaging the kids into thinking and trying to solve something" and that she wanted "to have them ask a questions first, so that they're thinking about something while they're doing it, instead of just doing it because I told them to" (Whitney, Int. 1.1, 740–745). Responding to a fictional scenario about the circuits lesson, Whitney stated, like Lisa, that it was important to "get [students] to think about what's going on besides 'oh, my light bulb lit, my light bulb didn't work"' and elaborated on what she felt explanatory questions would elicit from students, saying,

> Thinking about "why did it light?" and the concepts behind it, instead of just, "I made my light bulb light today," [to be able to say] "I made my light bulb light because I did this and it only worked because of this reason, or it only worked because everything is connected, electricity has to flow in a circle," being able to say that (Whitney, Int. 1.1, 1589–1594)

Responding to another scenario, Whitney discussed the importance of leveraging an investigation question throughout a given investigation or lesson, saying,

> I think [the teacher] has to make sure that she has questions to write on the board to get the students to focus . . . it's going to go towards her goal of the lesson [and] making sure that she's asking a question that they can answer with the experiment. (Whitney, Int. 1.2, 779–780).

More than the other teachers, Whitney prioritized using questions to make in-school science learning experiences engaging and applicable to students' lives outside of school. She explicitly described this as a crucial component of her view of the purpose of science learning, saying, "[students] have to make connections to their lives be able to say hey, I remember when we did that, that's what this is, being able to connect it to their lives, to new things later" (Whitney, Int. 3.3, 735–737). Whitney viewed emphasizing connections to real life as an important way to generate and sustain students' interest. She noted that questions were important to "get the students interested in what they were going to do" (Whitney, Int. 1.2, 772–773). She noted that effective investigation questions, for example, should be motivating and generate students' interest, saying

> some kind of question that they get interested in . . . and they're going to be like, hey, I want to figure out what these things do, and then, why? If I was a kid, I'd be like, I'll do it because you told me to, but I don't really have an interest in what the result is. (Whitney, Int. 1.2, 802–804)

Whitney suggested that she wanted "to try and use [questions] more to keep students interested in doing science" because "if they have a question they want to answer, I think that will even motivate them even more" (Whitney, Int. 2.1, 328–330). Whitney indicated that she believed she would be better able to develop driving questions as she gained more experience teaching the content of her curriculum, saying, "I think that as I get more comfortable with material, I can think of bigger questions that will be easier to answer with the material than right now" (Whitney, Int. 2.1, 321–322).

Over time, Whitney began to allude to a difference between specific questions and broader questions. For example, in responding to a scenario in her second year, she again indicated that she liked the idea of a question but not the wording, saying,

> that's a very quite concrete question. [You could] start with something that's going to get their interest to get their attention more, and then say "I want you to figure out first this [question] and then we'll try and answer this bigger question." (Whitney, Int. 2.2, 1313–1315).

Here, Whitney is describing how lesson-specific questions are meant to guide individual investigations that should be answerable within those investigations but, ultimately, these questions should lend themselves toward addressing less-specific, broader unit-level questions. This continued in Whitney's third year, where she began to elaborate more fully on the distinction she was making between broader questions meant to engage students and pique their interest and those that were concrete, lesson-specific, and directly related to the phenomenon under investigation. Using more general questions, Whitney described how students could then engage in the investigation to answer a more specific derivation of it, saying,

> ask a broader question first and then come down to okay, we're going to work with these things to figure this out and then at the end of this we'll discuss and then I want you to be able to answer this question at the end. (Whitney, Int. 3.1, 1936)

This nested questioning became an important aspect of Whitney's beliefs about the use of questioning to not only support students' sense-making about science but also to make science learning meaningful and applicable to students' lives outside of school. She began to see driving questions as a tool through which to accomplish these goals. When asked why using these broader questions was important, she said,

> because it will require them to think more and maybe if you can tie it into things that they would see, like [the teacher in the scenario] ties it in at the end, they're supposed to go home and tie this what they did in class today to how the lighting in your homes work. (Whitney, Int. 3.1, 1945–1949).

She noted that "that's the importance of the bigger question that's more connected to real life" (Whitney, Int. 3.3, 1720). When asked to clarify what she meant by a "bigger question" and explain why this was important, Whitney elaborated, saying,

> I think it needs a bigger question just to make the kids tie it into something real life instead of making it just a fun activity we did today in science, making it something that this is how this works and this is why this works . . . because if it's just a fun activity they did they might not . . . going to necessarily remember the science behind it unless you connect it, help connect it for them or show them how this experiment fits into the larger scheme of things. (Whitney, Int. 3.3, 1714–1720)

As this quote illustrates, Whitney's emphasis on making in-school science learning relevant and applicable to students' experiences outside of school had become an important factor in her talk about the use of driving questions and investigation questions.

In sum, similar to Lisa and Catie, Whitney prioritized the use of anchoring questions to provide a focus for students and promote student sense-making. However, in addition, she also believed these questions were effective tools for helping students make connections between school science and life outside of school. Early in the study, she did not differentiate between driving questions and investigation questions. Over time, however, she began to see driving questions as a means through which to accomplish her goal of relating science to students' lives by relating them to lesson-specific investigation questions that supported students' sense-making. In this way, Whitney's beliefs about the use of anchoring questions evolved in light of her foundational beliefs about the purpose of elementary science teaching and learning.

Brooke. Like Lisa, Catie, and Whitney, Brooke discussed using driving questions and investigation questions to promote student sense-making and to make the purpose of investigations and science learning opportunities explicit to students from the beginning of the study. She described how the effective use of questions and questioning was an important component of effective science teaching, saying it involved, "making sure the question is clear and that [students] understand they're supposed to be looking at about what happens" (Brooke, Int. 1.3, 1225–1226). She noted that she felt driving questions were important to "spark [students'] interest that they're going to want to answer. . . that has lasting capabilities to drive a whole unit" (Brooke, Int. 1.1, 741–742). She also discussed how these questions were also important for her planning and teaching, saying, "they help me to focus my thoughts as far as what I want the students to be able to do" (Brooke, Int. 1.2, 292). Brooke noted that the use of anchoring questions was an explicit goal she had for her students, saying,

> I want them to be able to do that sort of thing because that's what they're missing, that you have a question, you want to drive to answer it. I want them to have that idea because I do value the method of science as the goal to answering questions (Brooke, Int. 1.1, 730–734)

Despite her desire to engage students in scientifically oriented questions, Brooke cited a number of challenges she believed she faced in doing so. First, Brooke perceived using a question-driven approach to science teaching as a challenge for her particular group of students. She indicated throughout her first year that her students were not accustomed to inquiry-based science. She expressed frustration with early attempts to use questions to elicit her students' existing ideas and was concerned that using open-ended driving questions and investigation questions would be ineffective, saying, "I worry about these kids with the open-ended questions . . . I kind of wonder how far I would be able to get with that method. But it would be something I would be willing to try" (Brooke, Int. 1.1, 721–725).

Second, like the other three teachers, Brooke noted that her science curriculum materials did not include driving questions and investigation questions. As a result, she realized she would have to engage in some degree of curriculum adaptation to engage students in scientifically oriented questions, saying, "part of it is it would be the restructuring of the units in a way" (Brooke, Int. 1.1, 699). However, the time demands of being a first-year elementary teacher weighed heavily. She acknowledged that the prospect of developing anchoring questions to infuse in her existing curriculum materials was a daunting task because "... it is a bit of a time constraint ... I don't have the time to plan whole units ... because I'm planning basically six subjects for every day" (Brooke, Int. 1.1, 702). Brooke also reported feeling unprepared to develop effective anchoring questions, particularly driving questions, saying,

> I'm not sure I could find questions that would have those qualities for the units that I'm teaching. I have problems finding ways to link it all together for them and finding a question that's going to drive the whole unit of study that they would want to answer, linking what they're supposed to know but still making it of interest to them. (Brooke, Int. 1.1, 742–750)

However, at the end of her first year, Brooke said that she wanted to find ways to incorporate driving questions and investigation questions (which she, like Lisa, often referred to as sub-questions) in her science units, saying,

> I'd like to incorporate more of the driving questions for units. And having the sub-questions for each, like every lesson or two because I feel that that creates more of a cohesive body of knowledge for the students when they are able to answer something they're able to see how the information connects. So I'm definitely going to be looking for ways that I can incorporate and create the driving questions and the sub-questions. (Brooke, Int. 1.2, 1110–1114)

As with Catie and Whitney, Brooke believed that having science curriculum materials that included anchoring questions would facilitate her actual use of these questions. She noted that CASES units, which did include a unit-level driving question and specific investigation questions, helped her employ questions in productive ways. She said,

> I found the driving question page [on the CASES website] very useful. I wanted them to be able to answer these questions. One of the difficult things is to come up with these all encompassing questions that will allow the students to think and apply what they've been learning. So I found the driving question page really helpful (Brooke, Int. 1.2, 287–291)

Brooke said that "when the question's already there, it's a little easier than having to come up with your own" (Brooke, Int. 3.1, 233). She specifically recalled how using CASES curriculum materials supported her to incorporate driving questions, saying, "It's easier because it's more there. There's more support in it, we have the driving question with CASES" (Brooke, Int. 3.1, 230–232).

In her third year, unlike her first 2 years, Brooke's beliefs began to shift as she began to discuss a desire to have her students take more responsibility for their learning and engage in more student-directed inquiry. She began to describe effective science teaching as

> when the kids get a chance to be fully involved in the exploration ... not just sitting listening but they're identifying, they're classifying, they're exploring, they're experimenting and they are making decisions for themselves about what is important information and what are important conclusions to draw on. (Brooke, Int. 3.2, 610–616)

She noted that this was an area for professional growth that she was beginning to focus on, saying, “I still think I need to improve on having more opportunities for the kids to discover it themselves. Yes I’m getting some in there, but I think I could still do more of them figuring out for themselves” (Brooke, Int. 3.2, 646–652).

Brooke’s developing ideas about effective science teaching carried over into her discussion of driving questions and investigation questions. She began to view questions as a tool that could support her students to engage in more student-directed inquiry but also continue to allow her to make the purposes of science learning experiences explicit to students and address particular predetermined learning goals in her science teaching. Brooke noted in a scenario critique that the investigation question was “open-ended but it still gives them some guidance. So I like that they still have a chance for their own discovery but they know that’s what they’re supposed to be doing” (Brooke, Int. 2.2, 982). She also began to discuss how investigation questions could be conceptually and experientially linked across lessons and investigations. In a scenario critique late in her third year, she noted,

> I’d love to see some kind of question that asks ‘how might you change what you saw?,’ just so they can make some predictions about how you can change the outcome of the experiment before moving on. I think it’s important for them to become more involved in just doing science. Part of science is questioning and wondering what else could happen. What would happen if we did this? What, what could I do to change it? I want them questioning themselves and trying to come up with that on their own and being more involved in the process of science. (Brooke, Int. 3.2, 872–878)

In this way, Brooke had begun to view questions as an important tool for promoting more student-directed inquiry while still supporting them to make connections across the curriculum and having the purposes of investigations explicit.

In sum, Brooke, like the other three teachers, emphasized the use of anchoring questions to provide a sense of purpose and promote student sense-making. She initially expressed a lack of confidence in her ability develop questions that were broad enough to maintain curricular coherence across lessons and investigations but reported developing her ability to do so over time. By the end of the study, Brooke’s beliefs about effective science teaching had evolved such that she began prioritizing a more student-directed approach to teaching science as inquiry. As her beliefs about science teaching shifted, so too did her beliefs about the use of anchoring questions to support these practices.

Summary of Results

The four beginning elementary teachers in this study expressed ideas about the use of driving questions and investigation questions in science teaching that are consistent with those advocated by science education reform. In particular, they noted the important role these types of questions play in framing science units and lessons, particularly their capacity to convey purpose to students and promote student sense-making about scientific phenomena. However, while their ideas about the role of driving questions and investigation questions in science teaching were in some ways consistent, each teacher’s perspective on these two primary purposes for using driving question and investigation was unique. Furthermore, the teachers’ beliefs about questions and questioning evolved over time in respect to their other beliefs about effective science teaching and in light of perceived affordances and constraints of their individual classroom contexts.

SYNTHESIS AND DISCUSSION

In this study, we investigated four beginning elementary teachers' beliefs about the use of driving questions and investigation questions and how these beliefs evolved over the first 3 years of their professional teaching careers. Across the four teachers, three findings stand out in answering our research questions. First, as promoted in the methods course each had taken as a preservice teacher, the beginning teachers increasingly emphasized the use of anchoring questions in elementary science teaching over time. Across the four teachers, two fundamental rationales for using anchoring questions were evident in their espoused beliefs: to promote student learning about scientific phenomena and to make explicit the purpose of individual investigations or student learning experiences. Each of them emphasized using such questions in an explanatory way by drawing on "how" and "why" questions rather than descriptive questions. Throughout the study, the teachers highlighted the importance of not only introducing driving questions and investigation questions at the beginning of units and individual lessons but also returning to these questions after engaging students in experiences with scientific phenomena. As Krajcik and Mamlok-Naaman (2006) argue, these are two foundational features of an effective driving question that is "meaningful and important to learners and serves to organize and drive activities" and through which students "develop understanding of key scientific concepts associated with the project" (p. 213). The increasing emphasis the teachers placed on using questions to promote sense-making is an encouraging finding since questioning and the use of questions, particularly the use of anchoring questions, was emphasized in the four teachers' elementary science teaching methods course as a crucial component of inquiry-based teaching and learning.

Second, even though the four teachers shared a general commitment to these two themes, they each followed a unique trajectory in the evolution of their beliefs about the use of driving questions and investigation questions that coincided with the development of their perceived capacities to engage in effective science teaching in their classrooms. Lisa, for example, prioritized the structural role that questions could play consistent with her prioritization of objectives for student learning. Catie, while also emphasizing the importance of anchoring questions as sense-making tools, over time expressed a dissatisfaction with the use of these questions to elicit students' ideas. For Whitney and Brooke, their evolving beliefs about the use of anchoring questions were consistent with distinct but related beliefs they held about effective science teaching. Whitney sought to make science in the classroom accessible and relevant to students' lives outside of school and, over time, began to prioritize the use of driving questions toward that end. Brooke expressed a desire to use questions to help students make connections across individual learning experiences and, later, to scaffold them in taking more responsibility for their own science learning. Again, using anchoring questions to help students apply science to their lives and link scientific concepts in the classroom are two important affordances of such questions (Krajcik & Mamlok-Naaman, 2006), suggesting that these teachers' beliefs about the use of anchoring questions were largely consistent with those posited by the field. These findings also provide further evidence that beginning elementary teachers' developmental trajectories are unique and mediated by other beliefs and priorities (Forbes & Davis, in press).

Third, these teachers also highlighted affordances and constraints of their individual professional settings as tensions in their beliefs about the use of driving questions and investigation questions. This finding is consistent with existing research that shows teachers often struggle to translate their espoused beliefs into classroom practice because of local contextual features (Brown, 2009; Lotter et al., 2007). For example, beginning teachers rely heavily on the curriculum materials they have access to and often use a variety of curriculum materials (Forbes & Davis, in press; Valencia, Place, Martin, & Grossman, 2006). Each of the four teachers here alluded to and explicitly discussed the absence of driving questions and investigation questions in the science curriculum materials they used. This presented them with a number of challenges. For Lisa, it meant developing anchoring questions to complement her curriculum standards when she felt they did not facilitate inquiry-oriented teaching and learning. Brooke and Whitney initially noted that a lack of comfort and familiarity with the science content they taught influenced their perceived ability to effectively develop anchoring questions. Catie's curricular context initially afforded her opportunities to develop confidence in her use of anchoring questions but, after moving schools, perceived expectations to adhere to the school's curriculum and teach at a consistent pace with other teachers became significant constraints for her. In all cases, however, the teachers acknowledged that curriculum materials that included anchoring questions were helpful supports for their instructional planning and made the prospect of modifying and using these questions much more feasible.

IMPLICATIONS AND CONCLUSION

There are increased calls for teacher education research that can establish empirical relationships between teacher education programs, teacher learning, and, ultimately, student learning (Zeichner, 2005). If student learning is facilitated by teachers' classroom practice, and teachers' classroom practice is, in part, a function of their beliefs as some research indicates (e.g., Fishman et al., 2003; Lotter et al., 2007; Roehrig et al., 2007), then one important goal of science education research is to study how ideas promoted in science teacher education become tools employed by practicing teachers. This study, while a first step in a longer-term research agenda, is clearly limited by the small number of teachers involved, selection bias resulting from their positive inclinations toward science teaching and willingness to participate in the study, as well as by the nature of the data used. However, while these findings are not generalizable to all beginning elementary teachers, they are in an important contribution to research focused on better understanding how beginning elementary teachers articulate principles of inquiry-based science teaching and learning over time during this critical phase along the teacher professional continuum.

While there are still questions as to the lasting impact of teacher education on teachers' espoused beliefs and practice (Richardson, 1996), findings from this study suggest that the emphasis placed on the use of driving questions and investigation questions in the elementary science methods course taken by these four teachers continued to influence their beliefs about the role of such questions in their science teaching. Science teacher education experiences that emphasize teaching science as inquiry in line with current science education reform, including engaging students in scientifically oriented questions through the use of driving questions and investigation questions, can have a lasting influence on teachers' beliefs and orientations toward science teaching practice. However, even if teachers' beliefs are reasonably consistent with those promoted in science education reform, they need ongoing support to put those beliefs into practice. To be effective, teachers need to develop robust pedagogical design capacity for science.

However, teachers' pedagogical design capacity is not merely a function of their beliefs and knowledge (e.g., Magnusson et al., 1999), but how they employ these propositions as tools alongside effective curricular materials within professional contexts that afford effective science teaching practice (Brown, 2009). Teachers often engage in more teacher-directed, monologic forms of discourse in response to limiting elements of their pedagogical design capacities, such as their subject-matter knowledge (Carlsen, 1992). More experienced teachers, who have had time and experiences through which to develop such expertise, tend to use more open-ended questions and fewer recall questions (Morrison & Lederman, 2003). It is this shift from descriptive to explanatory questions that also marks a shift from monologic to dialogic patterns of discourse, the latter of which is a hallmark of scientific inquiry in secondary (Lemke, 1990; Polman, 2004), middle (Hogan et al., 1999; Kelly & Crawford, 1997; MacKenzie, 2001), and elementary classrooms (Gallas, 1995; Metz, 2008; van Zee et al., 2001; Wells & Arauz, 2006). Evidence from this study reinforces and extends existing research, illustrating how teachers' development of pedagogical design capacity for science teaching was a necessary precursor to their perceived capacity to develop and effectively employ anchoring questions.

One important means through which to support teachers' effective use of anchoring questions would be through science curriculum materials that incorporate driving questions and investigation questions. As Kesidou and Roseman (2002) found in their review of middle school science curriculum materials, most do not include anchoring questions that are revisited and retain relevance throughout longer-term instructional sequences, such as full science units. Our findings in this study indicate that the same was true for these four elementary teachers. With the exception of the CASES curriculum materials they used, they consistently reported not having access to science curriculum materials that included driving questions and investigation questions. These findings therefore illustrate the importance of including driving questions and investigation questions in reform-based science curriculum materials (Geier et al., 2008; Krajcik & Blumenfeld, 2006; Krajcik & Mamlok-Naaman, 2006).

However, to meet the needs of any given teacher, curriculum materials need to be conducive to adaptation, or be flexibly adaptive (Barab & Luehmann, 2003; Fishman & Krajcik, 2003). The ways in which these four teachers' beliefs about the use of driving questions and investigation questions were mediated by their beliefs, knowledge, and unique contexts reinforce the notion that no single set of science curriculum materials can be perfectly suited to a given teacher. Even though they each espoused beliefs about the importance of using driving questions and investigation questions, educative supports designed to explicitly support teacher learning (Davis & Krajcik, 2005) could help scaffold their decision making about how and why to modify the questions they use and how to infuse questions, particularly driving questions, into classroom activity over extended periods of time. These findings illustrate opportunities for science curriculum developers to support beginning elementary teachers' use and formulation of driving questions for science teaching by designing science curriculum materials that are conducive to classroom-based adaptation.

In sum, this research illustrates how four beginning elementary teachers prioritized the use of anchoring questions to engage students and promote student sense-making but did so in unique ways by negotiating their beliefs about the use of anchoring questions with their other beliefs, knowledge, and teaching contexts over time. Findings from this study provide much needed insight into teacher learning during induction phase of their professional careers (Feiman-Nemser, 2001; Luft, 2007; Putnam & Borko, 2000) and add to a growing body of research focused on teachers' beliefs about classroom inquiry, specifically engaging students in scientifically oriented questions. To help teachers build upon beliefs that are consistent with the field's conception of the effective science teaching, including the use of scientifically oriented questions, beginning teachers need science curriculum materials that include anchoring questions and opportunities to develop expertise required to use, modify, and develop driving questions and investigation questions effectively. Supporting beginning teachers in this way will help them confront challenges they face in teaching science as inquiry and move elementary science teaching closer toward the goals set forth in current science education reform.

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REFERENCES

Abell, S. K., Bryan, L. A., & Anderson, M. A. (1998). Investigating preservice elementary science teacher reflective thinking using integrated media case-based instruction in elementary science teacher preparation. Science Education, 82(3), 491–509.

Appleton, K., & Kindt, I. (2002). Beginning elementary teachers' development as teachers of science. Journal of Science Teacher Education, 13(1), 43–61.

Barab, S. A., & Luehmann, A. L. (2003). Building sustainable science curriculum: Acknowledging and accommodating local adaptation. Science Education, 87, 454–467.

Beyer, C., & Davis, E. A. (2008). Fostering second-graders' scientific explanations: A beginning elementary teacher's knowledge, beliefs, and practice. Journal of the Learning Sciences, 17(3), 381–414.

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

Carlsen, W. S. (1992). Closing down the conversation: Discouraging student talk on unfamiliar science content. Journal of Classroom Interaction, 27(2), 15–21.

Coburn, B. (2004). Apples and oranges: A rejoinder to Smith and Siegel. Science and Education, 13(2), 583–589.

Crawford, B. (2007). Learning to teach science as inquiry in the rough and tumble of practice. Journal of Research in Science Teaching, 44(4), 613–642.

Davis, E. A. (2008). Elementary teachers' ideas about effective science teaching: A longitudinal study. In International perspectives in the learning sciences: Cre8ing a learning world. Proceedings of the Eight International Conference of the Learning Sciences—ICLS 2008. Utrecht, the Netherlands: International Society of the Learning Sciences.

Davis, E. A., & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. Educational Researcher, 34(3), 3–14.

Davis, E. A., Petish, D., & Smithey, J. (2006). Challenges new science teachers face. Review of Educational Research, 76(4), 607–651.

Davis, E. A., & Smithey, J. (2009). Beginning teachers moving toward effective elementary science teaching. Science Education, 93(4), 745–770.

Davis, E. A., Smithey, J., & Petish, D. (2004). Designing an online learning environment for new elementary science teachers: Supports for learning to teach. In Y. B. Kafai, N. Enyedy, A. S. Nixon, & F. Herrera (Eds.), Proceedings of the 6th International Conference of the Learning Sciences, ICLS 2004. Mahway, NJ: Erlbaum.

Dillon, J. T. (1985). Using questions to foil discussion. Teaching & Teacher Education, 1(2), 109–121.

Engeström, Y. (1987). Learning by expanding: An activity-theoretical approach to developmental research. Helsinki, Finland: Orienta-Konsultit.

Engeström, Y. (2007). Enriching the theory of expansive learning: Lessons from journeys toward co-configuration. Mind, Culture, and Activity, 14(1-2), 23–39.

Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum to strengthen and sustain teaching. Teachers College Record, 103(6), 1013–1055.

Fishman, B. J., & Krajcik, J. (2003). What does it mean to create sustainable science curriculum innovations? A commentary. Science Education, 87, 564–573.

Fishman, B., Marx, R., Best, S., & Tal, R. (2003). Linking teacher and student learning to improve professional development in systemic reform. Teaching and Teacher Education, 19(6), 643–658.

Forbes, C. T., & Davis, E. A. (in press). In F. Columbus (Ed.), Curriculum development.

Gallas, K. (1995). Talking their way into science: Hearing children's questions and theories, responding with curricula. New York: Teachers College Press.

Geier, R., Blumenfeld, P., Marx, R., Krajcik, J., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. Journal of Research in Science Teaching, 45(8), 922–939.

Hiebert, J., Gallimore, R., & Stigler, J. W. (2002). A knowledge base for the teaching profession: What would it look like and how can we get one? Educational Researcher, 31(5), 3–15.

Hogan, K., Nastasi, B. K., & Pressley, M. (1999). Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. Cognition and Instruction, 17(4), 379–432.

Howes, E. V. (2002). Learning to teach science for all in the elementary grades: What do preservice teachers bring? Journal of Research in Science Teaching, 39(9), 845–869.

Kelly, G., & Crawford, T. (1997). An ethnographic investigation of the discourse processes in school science. Science Education, 81, 533–559.
Kesidou, S., & Roseman, J. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review. Journal of Research in Science Teaching, 39(6), 522–549.
Koufetta-Menicou, C., & Scaife, J. (2000). Teachers' questions—Types and significance in science education. School Science Review, 81(296), 79–84.
Krajcik, J., & Blumenfeld, P. (2006). Project-based learning. In R. K. Sawyer (Ed.), The Cambridge handbook of the learning sciences (pp. 317–334). New York: Cambridge University Press.
Krajcik, J., Blumenfeld, P., Marx, R., & Soloway, E. (2000). Instructional, curricular, and technological supports for inquiry in science classrooms. In J. Minstrell & E. van Zee (Eds.), Inquiring into inquiry learning and teaching in science. (pp. 283–315). Washington, DC: American Association for the Advancement of Science.
Krajcik, J., & Mamlok-Naaman, R. (2006). Using driving questions to motivate and sustain student interest in learning science. In K. Tobin (Ed.), Teaching and learning science: An encyclopedia (pp. 317–327). Westport, CT: Greenwood Publishing.
Latour, B. (1999). Pandora's hope: Essays on the reality of science studies. Cambridge, MA: Harvard University Press.
Lemke, J. L. (1990). Talking science: Language, learning, and values. Norwood, NJ: Ablex.
Lotter, C., Harwood, W. S., & Bonner, J. (2007). The influence of core teaching conceptions on teachers' use of inquiry teaching practices. Journal of Research in Science Teaching, 44(9), 1318–1347.
Luft, J. A. (2007). Minding the gap: Needed research on beginning/newly qualified science teachers. Journal of Research in Science Teaching, 44(4), 532–537.
MacKenzie, A. H. (2001). The role of teacher stance when infusing inquiry questioning into middle school science classrooms. School Science and Mathematics, 101(3), 143–153.
Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. Lederman (Eds.), Examining pedagogical content knowledge: The construct and its implications for science education (pp. 95–132). Dordrecht, The Netherlands: Kluwer Academic Publishers.
Metz, K. (2008). Narrowing the gulf between the practices of science and the elementary school science classroom. Elementary School Journal, 109(2), 138–161.
Miles, M. B., & Huberman, A. M. (1994). Qualitative data analysis. Newbury Park, CA: Sage.
Morrison, J. A., & Lederman, N. G. (2003). Science teachers' diagnosis of understanding of students' preconceptions. Science Education, 87, 849–867.
National Research Council. (1996). National Science Education Standards. Washington, DC: National Research Council.
National Research Council. (2000). Inquiry and the National Science Education Standards: A guide for teaching and learning. Washington, DC: National Academy Press.
Nespor, J. (1987). The role of beliefs in the practice of teaching. Journal of Curriculum Studies, 19, 317–328.
Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. Review of Educational Research, 62, 307–322.
Polman, J. L. (2004). Dialogic activity structures for project-based learning environments. Cognition and Instruction, 22(4), 431–466.
Putnam, R. T., & 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.
Reiser, B. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. The Journal of the Learning Sciences, 13(3), 273–304.
Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. In J. Sikula, T. Buttery, & E. Guyton (Eds.), Handbook of research on teacher education (pp. 102–119). New York: Macmillan.
Roehrig, G. H., Kruse, R. A., & Kern, A. (2007). Teacher and school characteristics and their influence on curriculum implementation. Journal of Research in Science Teaching, 44(7), 883–907.
Sandoval, W., & Reiser, B. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. Science Education, 88(3), 345–372.
Tabak, I. (2004). A complement to emerging patterns of distributed scaffolding. Journal of the Learning Sciences, 13(3), 305–335.
U.S. Department of Education. (2007). Teacher Attrition and Mobility: Results from the 2004–05 Teacher Follow-up Survey. Retrieved September 2, 2008, from http://nces.ed.gov/pubs2007/2007307.pdf.
Valencia, S., Place, N., Martin, S., & Grossman, P. (2006). Curriculum materials for elementary reading: Shackles and scaffolds for four beginning teachers. Elementary School Journal, 107(1), 93–120.
van Zee, E., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. Journal of Research in Science Teaching, 38(2), 159–190.

van Zee, E., & Minstrell, J. (1997). Using questioning to guide student thinking. Journal of the Learning Sciences, 6(2), 227–269.
Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. London: Cambridge University Press.
Wells, G., & Arauz, R. M. (2006). Dialogue in the classroom. Journal of the Learning Sciences, 15(3), 379–428.
Wenger, E. (1998). Communities of practice: Learning, meaning, and identity. New York: Cambridge University Press.
Zeichner, K. M. (2005). A research agenda for teacher education. In M. Cochran-Smith & K. M. Zeichner (Eds.), Studying teacher education: The report of the AERA panel on research and teacher education (pp. 737–757). Mahwah, NJ: Lawrence Erlbaum Associates.