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 scientific inquiry. To better support beginning elementary teachers' learning to engage students in inquiry-oriented science, particularly supporting students to ask and answer scientifically-oriented questions, it is necessary to learn more about how they negotiate the use of questions and questioning at this crucial stage of the teacher professional continuum. Four beginning elementary teachers were studied longitudinally over their first three years of professional teaching. Results show that they differentiated between a variety of types of questions in science instruction, including driving questions and investigation questions. While each teacher cited the importance of driving questions and investigation questions to establish purpose and promote student sense-making, they followed different trajectories in their learning to formulate and use driving questions and investigation questions. Evidence from this study suggests lessons learned in preservice teacher education had a lasting effect on the teachers' beliefs about questions and questioning and that science curriculum materials and their professional knowledge were important supports in their perceived capacity to formulate and use such questions. These findings have important implications for our understanding of teacher learning along the teacher professional continuum and help inform research on teachers and teaching, as well as teacher education and science curriculum development.

Questioning is a critical practice that lies at the heart of teaching. From cogenerative dialogue used by Greek scholars and philosophers centuries ago, questions have served as crucial discursive tools in educational contexts. One important role of questions is to elicit students' existing ideas, problematize them, and engage students in learning experiences designed to build upon their existing ideas (Driver, Guesne, & Tiberghien, 1985; Metz, 2000). Discourse founded in questions and questioning is also effective in that it harnesses children's natural desire to learn about the world around them. As Dewey (1916) noted many years ago, "where children are engaged in doing things and in discussing what arises in the course of their doing, it is found, even with comparatively indifferent modes of instruction, that children's inquiries are spontaneous and numerous" (pg. 232). As such, questions are essential tools that can be used to promote student learning (Hamilton & Brady, 1991; van Zee & Minstrell, 1997).

The use of questions and questioning is prioritized in current science education reform which emphasizes standards-based, inquiry-oriented science teaching and learning (Krajcik, Blumenfeld, Marx, & Soloway, 2000; National Research Council, 1996; 2000). Scientifically-oriented questions and related questioning practices are fundamental to inquiry-oriented science teaching and learning where 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. Scientifically-oriented questions can serve to anchor entire science units. These *driving questions* are crucial in project-based science to sustain students' interest and provide a motivating context for learning (Krajcik & Mamlok-Naaman, in press). Individual, lesson-specific *investigation questions* support the use of driving questions by scaffolding students' investigations and helping link investigation-specific activity with broader unit-levels goals and objectives. However, despite the emphasis on engaging students in scientifically-oriented questions as a fundamental component of scientific inquiry, reform-based science teaching and learning unfortunately remains more often the exception than the norm in U.S. schools (Grandy & Duschl, 2007).

Teachers' beliefs and orientations are a particularly important mediator in determining how they engage in teaching practice (Fishman, Marx, Best, & Tal, 2003; Richardson, 1996; Roehrig, Kruse, & Kern, 2007). Teachers sometimes hold ideas and beliefs that are inconsistent with those advocated by science education reform (Davis, Petish, & Smithey, 2006). Even when teachers' ideas and beliefs about science teaching are aligned with those promoted in science education reform, they may still face obstacles to actually translating those ideas and beliefs into practice. Together, teachers' beliefs and knowledge, classroom-specific affordances and constraints, and the curricular tools they use constitute a teacher's *pedagogical design capacity* (Brown, in press), or their ability to identify and mobilize requisite resources, including personal resources and external curricular tools, to craft learning environments in light of identified goals or objectives. Better understanding teachers' beliefs about driving questions and investigation questions in inquiry-oriented science teaching and learning, as well as how they evolve over time, is an important first step in understanding how teachers actually translate these ideas into science teaching practice using resources at their disposal and in light of unique characteristics of their school and classroom contexts.

The purpose of this study is to learn more about beginning elementary teachers' beliefs about inquiry-oriented science teaching, specifically the use of driving questions and investigation questions, and how they develop during the induction phase of their professional teaching careers. Teacher learning remains an important focus for educational research. The field must learn more about teacher learning at all points along the teacher professional continuum (Feiman-Nemser, 2001). Doing so is an important first step in characterizing teachers' development of teaching expertise, which remains elusive (Berliner, 1986; Hiebert, Gallimore, & Stigler, 2002; Roth, 1998). Research on early-career teachers is particularly important because they possess needs that are unique from those of preservice and experienced teachers (Luft, 2007) and because these critical first few years of teaching are when teacher attrition is highest. 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 driving questions and investigation questions, how these beliefs are entangled in other knowledge and beliefs, and how they evolve over the study. Findings from this study will 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 will be an important contribution to research on teachers' beliefs about inquiry and new teacher learning.

Theoretical Framework

The use of questions, particularly driving questions and investigation questions, is a crucial component of inquiry-oriented science teaching. However, for teachers to engage students in classroom inquiry, they must possess beliefs about and orientations toward inquiry-oriented science teaching practice that are consistent with reform-based standards for inquiry. In the sections that follow, we first discuss research on the use of questions and questioning and then turn to research on teachers' beliefs.

Questions and Questioning in Classroom Teaching and Learning

A core element of teaching and learning involves relating experiences over varying timescales through discourse and the production of relevant artifacts (Barab & Roth, 2006; Engeström, 1987; Lemke, 2000). 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). In order 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. As MacKenzie (2001) argues, “students need to learn how to question phenomena, that is, to engage the material world through dialogue” (pg. 144). Questions are an important element, if not the critical element, of classroom discourse aimed at the social construction of meaning (Vygotsky, 1978). Questions serve to link present activity with past and perceived future activity by explicating the contradictions that drive learning. They also help define the zone of proximal development and bridge the gap between socially-accepted knowledge and that which remains tentative.

Questions can be of different types and serve many different roles. Teacher-student dialogic interactions, which involve the use of questions, follow semi-consistent patterns that are dependent on the types and purposes of questions used. These discursive patterns serve as cultural tools and are therefore inexorably tied to the nature of classroom activity (Lemke, 1990; Polman, 2004; van Zee & Minstrell, 1997; Wells & Arauz, 2006). Questioning is often the first step 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 (Polman, 2004). As previous research has shown, teachers tend to emphasize these descriptive, confirmatory questions to help students arrive at predetermined learning goals (Koufetta-Menicou & Scaife, 2000; Morrison & Lederman, 2003).

While descriptive questions and patterns of questioning have an important role to play in classroom learning, they must be used in conjunction with more open-ended, dialogic patterns of classroom discourse (Polman, 2004). Such discourse involves the use of many types of questions, particularly open-ended questions, which unfold over different timescales and mutually inform one another. Negotiatory, dialogic patterns of discourse are defining characteristics of inquiry-oriented science teaching and learning in elementary and secondary classrooms (van Zee & Minstrell, 1997; Wells & Arauz, 2006). When inquiry is prioritized, reasoning and discursive patterns in science classrooms should mirror those of scientific community. These dialogic activity structures scaffold students’ knowledge construction by structuring the task of problem-solving and problematizing subject matter (Reiser, 2004; Tabak, 2004). Ultimately, student sense-making and explanation-construction are linked explicitly to questions that guide their investigations (Krajcik & Blumenfeld, 2006; Krajcik & Mamlok-Naaman, in press; Sandoval & Reiser, 2004). There is evidence that more experienced teachers may tend to rely less on recall questions and be more effective at promoting classroom discourse that supports inquiry (Morrison & Lederman, 2003).

One important type of question is that which is presented at the beginning of science units or individual lessons and serves to orient students’ learning activities. Unlike more in-the-moment patterns of questioning that are generally not predetermined, these driving questions and investigation questions are explicit, highly visible tools that serve to structure and guide learning activities over varying lengths of time. The use of driving questions, for example, has been a hallmark of the development of project-based science curriculum materials (Krajcik & Blumenfeld, 2006; Krajcik & Mamlok-Naaman, in press). Driving questions are presented and used throughout science units to engage and motivate students by presenting with a problem they perceive as worth investigating, support teachers to maintain curricular coherence, and promote student learning through explicit ties to standards and learning goals (Edelson, 2001; Krajcik & Blumenfeld, 2006; Reiser, 2004). Driving questions should be feasible, worthwhile, contextualized, meaningful, ethical, and sustainable to be effective. 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. We refer to driving questions and investigation questions more generally as anchoring questions.

Research on Teachers' Beliefs

Teachers' beliefs play an important role in how and why they engage in certain types of teaching practices (Borko & Putnam, 1996; Pajares, 1992; Richardson, 1996). A significant amount of evidence illustrates how teachers' ideas and beliefs influence the ways in which they construct science learning environments (Bryan, 2003; Haney, Lumpe, Czerniak, & Egan, 2002; Rosebery & Puttick, 1998) and the degree to which they engage in reform-minded science teaching practice (Roehrig, Kruse, & Kern, 2007). However, conflicting evidence suggests a disconnect between teachers' ideas and beliefs and their teaching practices (Bryan & Abell, 1999; Crawford, 1999; Haney & McArthur, 2002). As Davis and colleagues (2006) note, such discrepancies between espoused beliefs and actual classroom practice often occurs for one of two reasons. First, novice teachers may hold particular beliefs but not know how to translate those beliefs into classroom practice. Second, particular beliefs may be outprioritized by other beliefs considered more prescient by the teacher and by contextual factors that mediate how easily, if at all, certain beliefs can be translated into classroom practice. In both cases, the disconnect between, on the one hand, teachers' ideas and beliefs, and, on the other, their classroom practice, represents a site for ongoing teacher learning and fundamentally contribute to an individual teacher's pedagogical design capacity (Brown, in press).

Though there is conflicting evidence as to how and to what extent teachers' beliefs influence their practice, what does seem clear is that possessing beliefs consistent with models of effective science teaching promoted in current science education reform is an important first step for teachers to even be able to visualize inquiry-oriented science teaching practice. Elementary teachers tend to articulate views of effective science teaching that involve hands-on activities and emphasize making science engaging and enjoyable for students (Abell, Bryan, & Anderson, 1998; Appleton & Kindt, 2002; Howes, 2002). However, in regards to teachers' beliefs specifically about inquiry, findings from past research vary (Davis, Petish, & Smithey, 2006; Lederman, 1992). Some studies show that teachers possess beliefs about classroom inquiry and the nature of science that are reasonably robust and consistent with those advocated in current science education reform. Others, however, show that some teachers deprioritize teaching science as inquiry in light of other concerns, view inquiry as a linear, lockstep process, and do not generally acknowledge the social construction of scientific knowledge.

Despite the diverse beliefs teachers espouse about teaching and learning, there is encouraging research that shows how science teacher education can support preservice teachers to learn to teach science as inquiry (Crawford, 1999), including the effective use of questions. However, they face many challenges in learning to do so, particularly once they become practicing teachers. Increasingly, science has become deemphasized in elementary schools (Marx & Harris, 2006; Spillane, Diamond, Walker, Halverson, & Jita, 2001). Even when science is prioritized, beginning teachers may lack knowledge, skills, and beliefs necessary to engage in teaching practice in concordance with science education standards (Smith & Gess-Newsome, 2004). For example, elementary teachers in particular often struggle with insufficient subject-matter knowledge (Anderson & Mitchener, 1994; Cochran & Jones, 1998; Rice & Roychoudhury, 2003). Unlike most middle and secondary teachers, elementary teachers are usually faced with teaching many subjects in each school day, thus necessitating a substantial amount of instructional planning. As a result, beginning elementary teachers tend to rely heavily on curriculum materials they have been provided (Grossman & Thompson, 2004; Valencia, Place, Martin, & Grossman, 2006). However, other research has shown that beginning teachers often lack effective curriculum materials (Kauffman, Johnson, Kardos, Liu, & Peske, 2002), particularly those that promote the effective use of questions and questioning as a part of inquiry-oriented science (Kesidou & Roseman, 2002). Due to a lack of resources required to engage in inquiry-oriented science teaching (Appleton & Kindt, 2002), teachers may turn to using engaging but conceptually disconnected 'activities that work' (Appleton, 2003). In order to use anchoring questions effectively, investigations and activities upon which they're based must be coherent and experientially and conceptually linked.

Purpose of the Study

The purpose of this research is to characterize four beginning elementary teachers' ideas about and use of questions and questioning in their science teaching over the first three years of their professional teaching careers. While existing research on teachers' beliefs about inquiry-oriented science teaching does much to inform the field's understanding of teachers' beliefs about inquiry and the nature of science, Davis and colleagues (2006) point out a number of limitations of existing research. First, the majority of these studies have focused on preservice teachers and reinforce the importance of future research on beginning teachers (Luft, 2007). Second, while the literature on teachers' beliefs about the nature of science is substantial, many of the studies undertaken to investigate teachers' beliefs about inquiry-oriented science teaching have not done so explicitly using models of classroom inquiry articulated in science education reform documents (NRC, 1996; 2000). That is, existing research has not focused on teachers' beliefs and ideas about essential features of inquiry such as asking and answering scientifically-oriented questions. Here, we intend to address this gap in the literature by focusing on beginning elementary teachers' beliefs about 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' ideas about the use of driving questions and investigation questions in inquiry-oriented science teaching*? and *how do their ideas 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 three years of their professional teaching careers. These results are part of a larger, ongoing longitudinal study of seven beginning elementary teachers begun in the fall of 2002 and undertaken to better understand beginning elementary teachers' knowledge and science teaching practice, particularly inquiry-oriented teaching, their use of science curriculum materials, and their professional learning during this critical phase along the teacher professional continuum. The findings presented here add to other studies we have reported from this larger longitudinal research project (Beyer & Davis, 2006; Davis, 2008; Forbes & Davis, 2007; Stevens & Davis, 2007). The teachers in the longitudinal study, including those for whom results are presented in this paper, were voluntary participants.

Curriculum Access System for Elementary Science (CASES)

Elementary teachers have and will continue to require many forms of support to learn to teach science as inquiry in light of such challenges. In order 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 (Ball & Cohen, 1996; 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 National Research Council (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 teachers at this crucial stage of the teacher professional continuum by making innovative curriculum materials more flexibly adaptive (Barab & Luehmann, 2003; Fishman & Krajcik, 2003; Schwartz, Lin, Brophy, & Bransford, 1999), 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 members of the CASES research team. See Davis (2006) for a more detailed description of the program and elementary science teaching methods course.

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 multi-year 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 data collection 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 have been used for the teachers.

Catie. Catie began teaching in the fall of 2002 and completed her fourth year of teaching in June 2006. Throughout this study, Catie taught in private Catholic elementary schools. During her first year, she taught sixth grade in a relatively small school in an affluent suburb of a major metropolitan area nearby the university community. She noted her students were predominantly Caucasian, class sizes were relatively small, and she taught science at least four days a week. She described her school as "more traditional than reformed" and, as a result, "the subjects that we teach…we try and be flexible and creative but a lot of it is basics. They really want basic stuff" (Catie, Int. 1.1, 114-118)[1]. While students in every grade level at her school were assessed in science annually, she had a relative degree of freedom in choosing science content and designing instruction. During her first year, Catie had a full set of science textbooks and associated investigative materials from a major publisher.

Between her first and second years, Catie accepted a new second-grade position in a much larger Catholic elementary school. While demographically and culturally similar, the nature of her professional role shifted dramatically. Her class sizes were larger and she began teaching roughly twice as many subjects, leaving little more than a few half-hour blocks each week for science instruction. She noted that when she was hired, the principal at her new school told her that their science curriculum was very textbook-driven. In addition to receiving new science curriculum materials during her second year of teaching, she was provided another new set before her third year. Similar to those she used previously in her sixth grade teaching position, the science curriculum materials she used in years two and three were text-based materials from a major textbook publisher. She noted the pressure she felt to keep her instruction consistent with the other second-grade teachers and that a disproportionate percentage of instructional time went to mathematics and reading. Catie remained at this new school throughout the remainder of the study.

Lisa. Lisa began teaching in the fall of 2002 and participated in our study for the first three years of her teaching, during which time she taught fourth grade at a small, socioeconomically heterogeneous and predominantly Caucasian public elementary school. She described her school as one in transition. Her principal, who had only been at the school a few years before Lisa arrived, was committed to innovative reform and had attempted to reconstruct the professional culture of the school. Lisa described the faculty as split between veteran teachers with many years of experience and beginning teachers.

Over these three years, Lisa taught science roughly four times a week. In her first and third year she switched classes with another fourth grade teacher and had the opportunity to teach science twice per day. During her first two years, Lisa used a set of commercially-available science curriculum materials provided by her school. Instead of a single textbook,

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

these materials were organized around separate topical texts. She also noted that there were also comprehensive kit-based investigative materials associated with these texts but no lesson plans. Between her second and third year, Lisa's school purchased new science curriculum materials for fourth grade.

At the end of the third year, Lisa remained in her fourth grade teaching position but dropped out of our study.

Whitney. Whitney began teaching in the fall of 2002 and participated in our study for three years, her first three years of teaching. Throughout this time, Whitney taught fourth grade in a grade 4-8 public school on the West Coast that drew a very high population of military personnel and had a highly transient student and teacher population. Whitney assumed a number of leadership positions early on that would most often be reserved for more experienced teachers, such as mentoring a first-year teacher and becoming the grade-level chair at her school.

Whitney taught a wide variety of subjects. However, she taught the same six-week electricity and magnets unit six times each year. Whitney taught science, on average, two to three times a week for an hour and used kit-based science curriculum materials from a major curriculum developer. Whitney's school has relatively few resources and, as a result, many of her curriculum kits were consistently missing required resources.

Whitney moved after her third year of teaching, was unable to find a K-12 teaching position, and dropped out of our study.

Brooke. Brooke began teaching third grade in the fall of 2003 at a public K-5 elementary school in Florida. Her school's student population was largely low SES and highly transient, with a large number of ESL students. The school had very large class sizes and strongly emphasized students' performance on standardized tests. Over the three years during which Brooke was involved in this study, the schools' test scores fell such that by Brooke's fourth year of teaching, it was under formal corrective action to address the problem.

Brooke was a science minor in her teacher education program and appears to have a strong grasp of the nature of science, as well as a strong commitment to scientific inquiry. She had a textbook-based science curriculum but described herself as making "baby steps" toward becoming less textbook-oriented. She sought to move toward a more student-directed form of instruction. Brooke used terms like "hands on" and "discovery" to describe her goals with regard to her science teaching. However, Brooke felt constrained by her school context, specifically the fact that many of her students are English language learners, the relatively lack of resources for science teaching, and her school's emphasis on testing and content standards.

Brooke completed her third year of teaching in June of 2006. She remained involved in the longitudinal study until its conclusion.

Data collection

Three forms of data were collected in this study. First, semi-structured, audio-taped interviews were carried out with the teachers three times annually for three 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 (Appendix A)[2] were designed to provide the teachers an opportunity to describe their school settings, articulate their general views on science teaching and use of

[2] Interview protocols can be found online at http://www-personal.umich.edu/~ctforbes/NESTLIAppendices.pdf

science curriculum materials, and discuss their learning and development. During each of the interviews, the teachers were specifically 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 (Appendices B and C), were embedded features of the CASES online environment that the teachers accessed and completed through the website 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 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. The teachers varied considerably in how consistently they completed journal and daily log entries. Finally, the CASES website generated usage statistics that illustrated how often teachers visited the site, what pages and resources were accessed most often, and for how long. Because the three teachers were located in schools throughout the U.S., in-class observations were not logistically possible.

Data analysis

Each of the audio-taped interviews was transcribed, all CASES journal entries and daily log files were transformed into standard text documents, and CASES usage statistics were imported into statistical analysis software. 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). The first author begin data analysis by developing a coding key that was informed by existing research on questioning and classroom discourse (Koufetta-Menicou & Scaife, 2000; Morrison & Lederman, 2003) and dominant criteria relevant to inquiry-oriented science teaching as instantiated in the CASES curriculum materials and our own teaching and ongoing research efforts (e.g., Davis, 2006). After developing and testing numerous related coding keys, we finalized an initial coding key that guided comprehensive analysis. As analysis progressed, additional codes were added to account for emergent themes related to these dominant categories. Our final coding key is presented in Table 1.

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 multi-day 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 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

This study is focused on the teachers' beliefs about driving questions and investigation questions. However, it is also important to characterize the teachers' beliefs about other types and purposes of questions to position these beliefs within a broader set of beliefs related to the use of questions in inquiry-oriented science teaching.

As definitive patterns emerged, the data were reduced to isolate and illustrate key factors. This process continued until dominant themes had been refined and substantiated. 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 inter-rater 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 inter-rater reliability was 85%. After discussion, 100% agreement was reached.

Results

The findings presented here illustrate how these four beginning elementary teachers - Whitney, Lisa, Catie, and Brooke – each expressed unique ideas about the role of questions and questioning in inquiry-oriented science and reported using questions and questioning in light of these ideas. In answering our first research question, *what are beginning elementary teachers' ideas about the use of driving questions and investigation questions in inquiry-oriented science teaching*?, we found that they each prioritized the use of driving questions and investigation questions to promote student sense-making and make the purpose of science learning opportunities explicit to students. In addressing our second research question, *how do their ideas about the use of driving questions and investigation questions in inquiry-oriented science change over time*?, we found that the specific ways in which the teachers critiqued and reported using driving questions and investigation questions were uniquely embedded in the specific aspects of science teaching they each prioritized and influenced by their classroom contexts. In the results that follow, we first present in-depth case studies of each teacher and then discuss cross-case themes.

Teacher Cases

Lisa. Of the four teachers, Lisa's talk about the purposes of using driving questions and investigation 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 seemed to be heavily influenced by Lisa's experience teaching one of her first science units. After engaging her students in investigations using magnets, Lisa noted that students were struggling to make the goal explanations she had set for them, 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)[3]. 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 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. This trend is supported by findings from an earlier study in which Lisa prioritized learning goals and standards in her use of science curriculum materials (Forbes & Davis, 2007). From this point on, Lisa began to prioritize a more teacher-directed approach to science teaching.

Soon after this initial experience, Lisa began reporting using driving questions and investigation questions a majority of the time. She noted that she her teaching practices were

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

consistent from day-to day and reported that "I always pose a question" (Lisa, Int. 1.1, 649-650). Her reasons for doing so were in line with her goal of making the purpose of investigations explicit to students. She noted that such questions "keep the kids focused" and that "I like having a question to always focus the kids on" (Lisa, Int. 1.3, 556-560). Even by the end of her first year, the use of questions and questioning had become a fundamental part of Lisa's view of effective science teaching. 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)

This trend remained consistent throughout the study.

As she described her use of questions in her first year, Lisa not only prioritized questions as a way to orient students to the purpose of individual activities, but also began to emphasize questions which would lead students to construct explanations about scientific phenomena. Towards the end of her first year, Lisa described how she supplemented her curriculum materials with more explanatory questions. She noted that "a lot of times in my curriculum, they only want you to know this and this" and that she felt 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). In her critique of a fictional science teaching scenario, Lisa was critical of the investigation used by the teacher in the scenario, saying,

> 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)

Lisa described wanting to make sure that such questions promote student sense-making as well as serving as an anchor-point for instruction. In this example we see how 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 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 report using driving questions and investigation questions in her science teaching. She said that "the whole point of a lesson is centered around the question" (Lisa, Int. 3.2, 625-626) and continued to prioritize their use to make science learning meaningful and focused on student sense-making. She discussed the importance of having these questions explicitly written in students' science journals and the role they play throughout lessons, saying, "we'll read the question and talk about it…sometimes I come back to it at the end, sometimes we just kind of like talk about it throughout…sometimes we revisit it the next day" (Lisa, Int. 3.2, 618-624). Lisa also noted that the use of these questions supported her planning for science instruction, noting she, "looked at the sub-questions that the lesson's about and the objectives… after reading it then I decide…that's how I'm going to start my lesson, you know writing the sub-question on the board" (Lisa, Int. 2.2, 206-208). As the study progressed, Lisa 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 like 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 five 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). Data from Lisa suggest she not only continued to prioritize anchoring questions to explicate purpose and promote student sense-making, but that she planned to continue using these questions in significant ways in her science teaching.

Catie. Like Lisa, Catie began her first year of teaching with a set of experiences that influenced how she employed anchoring questions. In her first year, Catie's science curriculum was much less structured and specified than those described by the other three teachers. As a result, Catie was able to develop science units using a wide variety of curriculum materials. For example, during her first year, she developed a water quality unit centered around pollution in a local lake. An important aspect of this unit involved student research. She reflected that in an earlier activity in which she did not use explicit questions to guide students' research, students struggled to gather and organize information about the topic. She said that she "gave the kids articles, but left it more open-ended" and, as a result, "it was much more difficult for them" (Catie, Year 1 Journal, 21-24).

Based on this experience, she decided to incorporate anchoring questions much more explicitly in her water quality unit. She reflected that the questions she used helped make students' research much more productive, writing, "this time it was much more focused" and "having the questions kept them more focused and they were able to find the information easier and quicker" (Catie, Year 1 Journal, 26-29). Catie believed that the 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 seemed to reinforce the growing importance that Catie placed on driving questions and investigation questions. Afterward, she said “I think questions are very important…so students can focus” (Catie, Int. 1.1, 436). She also noted that having these questions were important support for her in developing her water quality unit. As we described in a previous study (Forbes & Davis, 2007), Catie engaged in a substantial amount of curriculum design for science in her first year. She said that the questions she used in her water quality unit helped “focus me as well 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).

As time went on, Catie continued to discuss the importance of using driving questions and investigation questions. She emphasized how “students need questions to guide their thinking during the tasks” (Catie, Year 1 Journal, 31) and to promote sense-making. In discussing an interview scenario in her second year, Catie highlighted the importance of using questions that required students to justify the claims that they make. She said, “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). As in her first year, Catie maintained an emphasis on using such questions to provide a purpose to investigations and promote student sense-making. She noted, “I think…the driving question is important so that they know why they’re doing the experiment and what they are supposed to gain out of it. What they are supposed to be learning from it while they’re doing it? I think it’s a good thing they have a question” (Catie, Int. 3.2, 522-529). This general orientation toward the use of questions was consistent with Catie’s critiques of the scenarios in her third year. For example, in response to one scenario, she said, “I think that [students] need some questions written on the board, specific questions or specific observations to make. I think like at the end it should be like, ‘well why do you think these things happened?’” (Catie, Int. 3.2, 268-217).

Despite the importance she placed on questions as a crucial component of scientific inquiry, and unlike Lisa, Catie reported using driving questions and investigation questions sporadically during her first year. This seemed to be in large part a function of the curriculum materials she was using. Though she developed driving questions for her water quality unit, she recalled a unit on flight she developed and taught later in her first year, and why she did not use a driving question, saying, “I didn't do it so much in [the flight unit] because the materials I had [and] I didn't have a lot of time to figure out where I wanted it to be…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. But there weren’t really any questions behind them” (Catie, Int. 1.3, 174-176). However, when using the CASES curriculum materials during her first year, she noted that she always used the driving questions and investigation questions. In a CASES matter unit Catie taught in her first year, she noted that “those questions not only anchored the lessons and the unit as a whole but they also acted as kind of like a focus for [students]” (Catie, Int. 1.3, 154-156). She suggested that having existing driving questions and investigation questions in the CASES curriculum materials was a helpful support for her, saying, “there’s 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).

Toward the end of her first year, Catie began to articulate frustrations with using driving questions and investigation questions at the beginning of units and lessons. Specifically, she was concerned about her students wanting to provide quick answers to anchoring questions based on their own prior knowledge rather than using the questions to guide current investigations. She described her experience using driving questions and investigation questions, saying, “a lot of times the kids will raise their hands, 'well I already know how that works' and they'll give me some short little phrase and I'll say, 'we're not going to talk about that right now, I want you to think deeper about it before you just give off some answers. It's not as simple as you think it is'" (Catie, Int. 1.2, 361-364). For example, while Catie had discussed the effectiveness of the driving questions in the CASES matter unit she taught, she also discussed challenges she had experienced using them, saying,

> The only problem that I found was that the kids were a little anxious with them, like they just wanted to answer the question right then and there. I tried to pull back and say well, "I know you have kind of a general idea of what the answer might be but we're going to investigate it a little more." They kind of got a little edgy about that…they're all like, "Well I know that answer."…and I said, "Well, let's dig a little bit deeper." (Catie, Int. 1.3, 136-139)

As Catie transitioned into her new position as a second grade teacher in her second year, her ideas about the use of driving questions and investigation questions continued to evolve. Similar to her first year, she reported not using driving questions when she taught science using her school provided science curriculum materials. However, unlike her first year, she also reported not using the driving questions and investigation questions in the CASES unit she taught either, saying, "I just use the lessons usually" (Catie, Int. 2.2, 454). As we have described elsewhere, Catie felt more constrained at her new school and less able to develop science units like she had in her first year teaching sixth grade (Forbes & Davis, 2007). This had an impact on how she used the questions in the CASES curriculum materials. Rather than using the CASES units as a framework for the units she taught, she indicated that she was now instead incorporating CASES lessons into her units based on her school-provided curriculum. 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).

In addition to reporting using driving questions and investigation questions less often, Catie continued to be concerned 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, 1308-13909).

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, this concern 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). In order 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 summary, while Catie consistently expressed beliefs about the importance of anchoring questions in science, she also reported using them less over time and wrestled with concerns that some students would attempt to provide quick answers to questions meant to guide learning experiences. At the end of the study, Catie continued to struggle with how to use anchoring questions in ways that were motivating and engaging for all 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 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. 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 having them answer a question, asking a question that they can answer with the experiment" (Whitney, Int. 1.2, 779-780). In discussing a scenario at the end of her third year, she again stated that "I like using a question because it gives them kind of a guide of where they're going" (Whitney, Int. 3.3, 1704).

More so than the other teachers, Whitney prioritized using questions to make in-school science learning experiences engaging and applicable to students' lives outside of school. In discussing one of her first enactments of her electricity and magnets unit, Whitney not only talked about the importance of using questions that promote students' understanding of how scientific phenomena occur, but also of the need for students to be able to apply this knowledge outside of school.

> …we were talking about how a circuit works, well, what's plugged in, in your house? What do you use electricity for? Why is it important? So that they have

> to not only be able to do the things in the classroom, but they also have to be able to apply that knowledge, so it's not them just necessarily telling me, they wrote down that attract means that the magnets will stick together. That they can explain to me 'what do they use a magnet for?' and 'how is it working?' (Whitney, Int. 1.1, 330-336)

Whitney viewed emphasizing connections to real life as an important way to generate and sustain students' interest. She noted that questions were important to "and 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).

While Whitney talked about the importance of questions to engage students and promote student learning, she reported using lesson-specific investigation questions only sometimes. When asked how often her science lessons were organized around questions, she said, "usually I'll ask them to do something with it, but it doesn't always start with a question…a lot of times I try to take a question off what they said at the beginning of the unit. And other times it'll be, today we're going to work on doing this" (Whitney, Int. 1.1, 427-429). While Whitney described using investigation questions at least sometimes, she noted she rarely used unit-level driving questions. This trend continued on into her second year. She said, "I'll give them little questions sometimes, but I don't usually have a big question, like a driving question" (Whitney, Int. 2.1, 322-323). Despite reporting not always using driving questions and investigation questions, however, Whitney suggested that she wanted "to try and use [questions] more to keep them 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 suggested that she would be better able to come up with 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, she commented on one of the fictional scenarios at the end of her second year, noting that it was effective for the teacher to start with a question to explicate the goal for the investigation. However, she also critiqued the specific question, saying, "the teacher's trying to get at a specific thing but I feel like the question gets a little bit more broad than that…it's having the question and then giving a couple of [other questions], you're trying to do this or even having it be like whichever group can make their sponge hold the most water" (Whitney, Int. 2.3, 2006-2008). In another scenario, 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 'we're going to figure out why this kind of thing works today, we're going to be working with these things, 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.

In Whitney's third year 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. In responding to another fictional scenario, Whitney criticized the teacher for not addressing driving questions once students had shared findings from an investigation and addressed the investigation question. She said,

> He asks these bigger questions but then they never really answered them. They just copied them down and had homework. I thought that if he came back to that question it would make the lesson like fit together better into like a bigger picture …eventually and it would probably make it also easier to answer the question if they have to answer at home. (Whitney, Int. 3.1, 2046-2060)

Later in her third year, Whitney critiqued the lightbulb scenario which included the investigation question "what are all the possible ways to light the bulb using just the wire and the battery?". She again noted that she thought it would be more effective to start 'a bigger question, maybe something more broad" (Whitney, Int. 3.3, 1707). Using this more general questions, Whitney described how students could then engage in the investigation to answer a more specific derivation of it, saying, "bring it down, 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 way for Whitney to use questioning to not only support students' sense-making about science, but also make science learning meaningful and applicable to students' lives outside of school. The ability of students to apply their knowledge to life outside of school was something Whitney had continued to prioritize. Toward the end of her third year, 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). She began to see driving questions as a tool through which to accomplish this goal. 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 he 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)

By the end of the study, Whitney had refined this thinking to incorporate investigation questions to support students' lesson-specific activity while using driving questions to make coherent instructional sequences relevant to students' lives. Her thinking was illustrated by her critique of a scenario at the end of her third year. The scenario describes an activity in which students design waterproof coverings for sponges to model water-retention in plants. Whitney critiqued the investigation question used in the scenario, saying,

> I don't know if I like it that much because it's kind of very based on what they're doing, so maybe if they had a bigger question behind it too, like a more overarching question, like 'how do plants in the desert survive?' and then he talks about this as part of it and then relates this stuff back to that question, then maybe it would be better. (Whitney, Int. 3.3, 1705-1709)

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.

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, "making sure the question is clear and that [students] understand they're supposed to be looking 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 something she 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 reported rarely using driving questions and investigations early in her first year. She cited a number of challenges 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 recalled "asking some of the more in-depth questions and just trying to get where they were on those ideas and finding they were nowhere on the ideas" (Brooke, Int. 1.1, 711-712). She 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, 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 she had also not yet begun to do so largely due to a lack of planning time, saying, "…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 described how she felt unprepared to effective develop 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 continue to find ways to incorporate driving questions and investigation questions in her science units. She said she was "finally feeling a little more in control" and could "take a deeper look at some of the things and restructure how I'm doing that" (Brooke, Int. 1.1, 703-705). Specifically, she said "I'm going to be looking at trying to do more of a questioning approach to it" (Brooke, Int. 1.1, 706). At the end of her first year, Brooke continued to emphasize establishing curricular coherence in her use of driving questions and investigation questions. She elaborated on her plans, 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)

Over time, Brooke reported beginning to use driving questions and investigation questions. In her first year, she taught a CASES astronomy unit and noted that "this is the first time I'd really used a driving question" (Brooke, Int. 1.3, 735). However, like Whitney, Brooke reported using anchoring questions only sometimes. When asked if she used driving questions and investigation questions every day in her second year, Brooke said, "not necessarily [though] a lot of times it will be a question" (Brooke, Int. 2.3, 1226-1230). This continued into to her third year where she noted using driving questions and investigation questions in some lessons and units but not others, saying, "I sometimes do it and I sometimes don't" (Brooke, Int. 3.2, 1170).

CASES curriculum materials were a major support for Brooke. As with Catie and Whitney, she reported that the CASES units, which did include a unit-level driving question and specific investigation questions, helped her employ questions in productive ways. In teaching her astronomy unit during her first year, she said,

> I found the driving question page [on the CASES website] very useful. I wanted them to be able to answer these questions and 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 and used the driving questions quite a lot. (Brooke, Int. 1.2, 287-291)

This trend continued throughout the study. Brooke noted that using curriculum materials that already included anchoring questions helped her actually use these questions, saying, "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. And so most of the time I do bring that in" (Brooke, Int. 3.1, 230-232).

Over time, Brooke continued to emphasize many of the same themes she had throughout the study. She stated that she believed questions were an important way to accomplish her goal conveying purpose to students, saying "I really like having a question because the students are looking for a purpose" (Brooke, Int. 3.2, 1149). She also continued to view them as a way of maintaining curricular coherence, noting, "a really good way to wrap up a lesson is to return to the question….it kind of creates that whole sense of completeness. I like having, a question to start us off and to kind of go back to" (Brooke, Int. 3.2, 1150-1151). She noted that doing so allowed students to "make connections to other units or other areas within the curriculum" (Brooke, Int. 3.2, 623). Her ideas about effective science teaching and her own science teaching practice suggests that she had begun to gain familiarity with the curriculum and to gain confidence in her ability to develop a more coherent and related set of science learning experiences for students. She said that "I think I was much more effective this year in helping the kids make those connections…because I purposely planned a step by step way so that the kids would learn the science content and then see something where they could connect it" (Brooke, Int. 3.2, 630-635).

However, unlike her first two years, as Brooke began to develop confidence in her ability to support students to make connections across the curriculum, she also 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, 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 summary, Brooke worked throughout the study to incorporate anchoring into her science teaching. 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 had begun to discuss the importance of anchoring questions as she shifted toward prioritizing a more student-directed approach to teaching science as inquiry.

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. These results show that while their ideas about the role of driving questions and investigation questions in science teaching were in some ways consistent, the teachers' general commitments to these two primary purposes for using driving question and investigation differed in respect to their own conceptions of effective science teaching and in light of affordances and constraints of their individual classroom contexts.

Synthesis and Discussion

In this study, we investigated four beginning elementary teachers' beliefs about the role and use of driving questions and investigation questions; how they negotiated their beliefs in light of other beliefs, knowledge, and perceived affordances and constraints of their teaching contexts; and how these beliefs evolved over the first three years of their professional teaching careers. As illustrated in the results, the four teachers in this study had unique ideas about the role of driving questions and investigation questions in science teaching that evolved in light of their experiences in the classroom and other beliefs they held. Across the four teachers, there are three findings stand out in answering our research questions.

First, in their beliefs about the use of driving questions and investigation questions, the teachers emphasized questioning to promote student learning about scientific phenomena and emphasized the importance of these questions to make explicit the purpose of individual investigations or student learning experiences. Each of them emphasized using 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 (in press) 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" (pg. 213). This is an encouraging finding since questioning and the use of questions, particularly the use of anchoring questions as a part of inquiry, was emphasized in the four teachers' elementary science teaching methods course.

Second, even though the four teachers shared a general commitment to these two themes, they each followed unique trajectories in their beliefs about the use of driving questions and investigation questions as their other beliefs and knowledge, as well as their perceived capacities to engage in effective science teaching in their classrooms, evolved over the three years of the study. Lisa, for example, prioritized the structural role that questions could play consistent with her prioritization of short-term and long term objectives for student learning that we have described elsewhere (Forbes & Davis, 2007). For Whitney and Brooke, their evolving beliefs about the role of these 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, in press), suggesting again that the teachers' beliefs about the use of anchoring questions were largely consistent with those posited by the field. These findings also reinforce results from other studies that found that individual teachers' learning trajectories in relation to a particular construct are unique because they are mediated by their pre-existing beliefs (Anderson, Smith, & Peasley, 2000).

Third, teachers often struggle to translate their espoused beliefs into classroom practice. This is often the result of local contextual features which mediate teachers' efforts to do so (Lotter, Harwood, & Bonner, 2007) and serve as an important contributor to a teacher's pedagogical design capacity (Brown, in press). It should come as no surprise that teachers also highlight these affordances and constraints of their individual professional settings as tensions in their beliefs about the use of driving questions and investigation questions. Past research has shown that beginning teachers rely heavily on the curriculum materials they have access to and often use a variety of curriculum materials (Forbes & Davis, 2007; Grossman & Thompson, 2004; Kauffman et al., 2002; Valencia et al., 2006). Each of the four teachers alluded to and explicitly discussed the absence of driving questions and investigation questions in the science curriculum materials they used and described having to develop their own. This presented them with a number of challenges. For Lisa, it meant developing anchoring questions to complement her curriculum standards which, as we have described elsewhere (Forbes & Davis, 2007), she felt 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, such as CASES curriculum materials, were helpful supports for their instructional planning and made the task of modifying and using these questions much more manageable.

Implications and Conclusion

Elementary teachers, particularly beginning teachers, face numerous challenges in engaging in reform-based, inquiry-oriented science teaching (Davis, Petish, & Smithey, 2006). One of these challenges is learning to translate their beliefs about science teaching into science teaching practice. As the literature of teachers' beliefs indicates, teachers negotiate their beliefs in practice and the often apparent disconnect between their beliefs and what they actually do in the classroom is mediated by features of their individual classroom contexts. As teachers develop over time, however, the ways in which they reconcile particular beliefs with other knowledge and beliefs, as well as affordances and constraints of their classroom contexts, may well evolve too. Our goal in this study was to characterize their beliefs about the use of driving questions and investigation questions, how they negotiated these beliefs in light of their views of effective science teaching and perceived context-specific affordances and constraints, and how these relationships changed over the course of the study.

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, at least in part, a function of their beliefs as some research indicates (e.g., Fishman et al., 2003; Roehrig, Kruse, & Kern, 2007), then one important goal of teacher education research is to study how ideas promoted in teacher education become tools employed by teachers as part of their pedagogical design capacity. However, there are still questions as to the lasting impact of science teacher education on teachers as they pursue their teaching careers after preservice teacher education (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 of the field, they need ongoing support to put those beliefs into practice. To be effective, teachers need a deep understanding of the content being taught (subject matter knowledge), how to teach that content effectively (pedagogical content knowledge), and of the curriculum standards and associated instructional materials (curricular knowledge) (Magnusson, Krajcik, & Borko, 1999; Shulman, 1986). In previous research involving Whitney and Lisa (Forbes & Davis, 2007), we found that both developed increasing PCK for the topics they taught. Evidence from this study suggests that the teachers' development of knowledge for teaching was a necessary precursor to their perceived capacity to develop and effectively employ anchoring questions. This may help explain why 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 the classroom (Lemke, 1990; Polman, 2004; Wells & Arauz, 2006).

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 seem to 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 (Krajcik & Blumenfeld, 2006; Krajcik & Mamlok-Naaman, in press).

However, in order to meet the needs of any given teacher, curriculum materials need to be conducive to adaptation, or be flexibly adaptive (Schwartz et al., 1999). 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 (Ball & Cohen, 1996; 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 and educative for teachers.

While these results shed light on many questions regarding beginning elementary teachers' beliefs about driving questions and investigation questions in science teaching, additional research should be undertaken to further explore this topic. To characterize teachers' learning at stages along the teacher professional continuum, subsequent studies should begin tracking teachers beliefs during their preservice stage and on through the induction years. Second, such research should be expanded by drawing upon classroom observations and artifacts that provide evidence for how teachers are able to translate such beliefs into classroom practice. Such research could characterize the types of driving questions and investigation questions teachers use, for example, in light of criteria for effective driving questions (Krajcik & Mamlok-Naaman, in press). It could also help understand how teachers use these specific types of questions as cultural tools in their classrooms over time in light of their science teaching practices (Polman, 2004; Wells & Arauz, 2006). Finally, further research should be carried out to assess the degree to which teachers' use of anchoring questions, as well as inquiry-based teaching more generally, ultimately contributes to student learning.

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) 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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