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Teacher Roles of Questioning in Early Elementary Science Classrooms: A Framework Promoting Student Cognitive Complexities in Argumentation

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Abstract The purpose of this study was to investigate the various roles that early elementary teachers adopt when questioning, to scaffold dialogic interaction and students' cognitive responses for argumentative practices over time. Teacher questioning is a pivotal contributing factor that shapes the role teachers play in promoting dialogic interaction in argumentative practice and that different roles serve different functions for promoting students' conceptual understanding. The multiple-case study was designed as a follow-up study after a 4-year professional development program that emphasized an argument-based inquiry approach. Data sources included 30 lessons focusing on whole class discussion from three early elementary teachers' classes. Data were analyzed through two approaches: (1) constant comparative method and (2) enumerative approach. This study conceptualized four critical roles of teacher questioning—dispenser, moderator, coach, and participant—in light of the ownership of ideas and activities. The findings revealed two salient changes in teachers' use of questions and the relationships between teachers' question-asking and students' cognitive responses: (1) teachers increasingly used multiple roles in establishing argumentative discourse as they persistently implemented an argument-based inquiry approach, and (2) as teachers used multiple roles in establishing patterns of questioning and framing classroom interactions, higher levels of student cognitive responses were promoted. This study suggests that an essential component of teacher professional development should include the study of the various roles that teachers can play when questioning for establishing dialogic interaction in argumentation and that this development should consist of ongoing training with systematic support.

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Introduction

The emphasis on argumentation in science education shifts the focus of science classrooms from memorizing facts to engaging students in an authentic scientific practice in which they search for data patterns to shape evidence for the support of scientific claims and debate those claims publicly to identify the weaknesses of their arguments (Cavagnetto 2010; Duschl 2008; Manz 2015; Sampson et al. 2011). The importance of argumentation has been explicitly endorsed by two recent U.S. reform documents, *Common Core State Standards* (National Governors Association Center for Best Practices and Council of Chief State School Officers (CCSSO) 2010) and *A Framework for K-12 Science Education* (National Research Council (NRC) 2012), as a critical approach utilized in science classrooms for promoting student conceptual understanding and cognitive thinking.

Argumentation can be seen as a social negotiation process that involves an interplay between constructing claims and evidence and critiquing them, and which takes place within a specific community (Driver et al. 2000; Mercier and Sperber 2011). In argumentative classrooms, students tentatively construct their claims supported by relevant, sufficient, and coherent evidence either as individuals or within a group. They then present those claims and evidence publicly to seek critique and confront alternative arguments in order to improve their own arguments (Ford, 2012). In this sense, the ultimate goal of argumentation in science classrooms is to advance student arguments and seek agreement through identifying deficiencies and errors in those arguments.

However, *A Framework for K-12 Science Education* (NRC 2012) raised the critical point that argumentation "has too often been underemphasized in the context of science education" (p. 44, NRC 2012). Previous research has shown that teachers often have difficulty in interacting with students in such dialogue-rich environments. McNeill and Pimentel (2010) observed that high school teachers used more closed and factual recall questions while implementing argument-based curriculum. They suggested that these kinds of questions disconnected students' ideas and tended to discontinue the direction of discussion. A national observation survey in the USA conducted by Banilower et al. (2013) found that more than 90 % of questioning patterns in science lessons consist of low-level "fill-in-the-blank" questions, asked in rapid-fire fashion to obtain the correct answer and move on, in effect short-circuiting student cognitive thinking. Scott et al. (2006) call this "authoritative discourse": a situation in which a teacher's purpose is to focus the students' full attention on a specific point of view. This is opposed to dialogic interaction (Bakhtin 1981), in which teachers acknowledge, explore, compare, and synthesize different perspectives presented and examine how these views are related to science core ideas.

Chin (2006, 2007) contended that teacher roles of questioning are a key factor of dialogic interaction in argumentative practice, and different roles serve different functions for promoting students' conceptual understanding and ownership of learning in science. That is, teachers play different roles when they ask different questions, and these roles significantly affect students' learning. For instance, when teachers ask more open-ended questions to encourage students to express their ideas and take responsibility for their own learning, the teachers may play the role of motivators to stimulate the generation of new ideas (Crawford 2000). When

teachers ask diagnosing questions, they may play the role of evaluators in order to discern student understanding (Ruiz-Primo and Furtak 2007). However, teachers struggle with developing appropriate and diverse roles for asking a series of high-quality questions to establish argumentative discourse and foster students' conceptual understanding and cognitive thinking (Oliveira 2010).

Developing appropriate and multiple roles of questioning in the establishment of dialogic interaction for argumentation is challenging and takes time (Martin and Hand 2009; Davis et al. 2006). Addressing this challenge requires examining teacher roles of questioning in the establishment of dialogic interaction as well as examining the dynamic interaction patterns among teachers and students that can influence students' cognitive responses (Oliveira 2010). Many studies of this subject have dichotomized the types of teacher questions into open- and closed-ended questions (e.g., Lee and Kinzie 2012), which may tend to oversimplify the role of teacher questioning in the complexity of dialogue in argumentation. This dichotomy also prevents teachers from developing multiple roles for argumentation. There is still much to be learned about supporting the development of teacher roles of questioning in promoting student students' cognitive responses.

In addition, the opportunities for early elementary students (grade 1–3) to participate in scientific argumentation are rare because young children are often assumed to have limited scientific reasoning abilities, process skills, and the conceptual knowledge necessary to engage in scientific practices (Lehrer and Schauble 2006; Metz 2011). Most previous studies have focused on upper elementary (e.g., Chen et al. 2013; Benus 2011), middle school (e.g., Chin 2007; Kawalkar and Vijapurkar 2013), high school (e.g., McNeill and Pimentel 2010; Osborne et al. 2013; Scott et al. 2006), and college students (e.g., Kelly and Takao 2002; Tsai and Tsai 2014). Consequently, little information currently exists on early elementary classrooms, even though research suggests that early elementary science practices are fundamental for developing cognitive thinking and scaffolding readiness capacities in multiple domains (Jordan and McDaniel 2014; Lee and Kinzie 2012).

This multiple-case study aimed to explore and conceptualize the roles of questioning that developed as early elementary teachers attempted to implement an argument-based inquiry approach over four successive years and how those changes in teacher roles related to student cognitive engagement in argumentation. The study was framed by the following research questions:

(1) What roles do early elementary teachers adopt in argumentative discourse, especially in whole class discussion, when they use questioning as a tool to engage students in cognitive responses over the course of 4 years?
(2) What are the relationships between the roles teachers adopt and students' cognitive responses?

Conceptual Underpinnings

Teacher Roles in Argumentation

Argumentation can be seen as a social negotiation activity in which members of a community make sense of the phenomena under study by proffering, critiquing, evaluating, challenging, and defending arguments through dialogue (Berland and Reiser 2011; Chin and Osborne

2010). The fundamental goal of argumentation in science classrooms is not only to interact/exchange ideas through dialogue but also to establish an agreement where teachers and students work together as a community to search for deficiencies in their arguments through solving cognitive conflict (Ford, 2012; Walton 1998). In this regard, argumentation in science classrooms is a form of dialogue that goes beyond interaction, as it includes cooperation and movement toward mutually accepted positions utilizing claims and evidence to debate and debunk competing ideas. Translating the practice to science classrooms, then, means that the pattern of classroom discourse must shift (Chen 2011; McNeill and Pimentel 2010). Traditional teaching has centered on the teacher being in charge of the talk and deciding what is discussed and what knowledge is allowed. Frequently, classroom discussion follows an Initiate, Response, Evaluate (IRE) pattern, in which the teacher normally takes the leader role by asking a question, a student responds to the question, and the teacher evaluates the student's response (Sinclair and Coulthard 1975). This conventional IRE pattern focuses on transmitting the correct answers to students and ensuring they are able to reproduce those answers (Henderson et al. 2015). Oliveira (2010) argued that the ubiquitous nature of this pattern may limit students to short responses and thus impede their higher-level cognitive thinking. Additionally, Polman (2004) concluded that this type of structure appeared to align most often with the teacher's authoritative role. In the IRE pattern, the teacher plays only one central role that involves controlling the whole class discussion to check whether students recite the answers. This discussion pattern is a monologue, lacking opportunities for students to debate and critique and giving students only limited ownership over their learning.

In argumentative classrooms, teachers cannot simply play one single role; they must listen to and elicit students' ideas so as to clarify them and scaffold students to construct acceptable scientific knowledge based on others' ideas (Oliveira 2010). Furthermore, they need to adopt the role of modeling how to justify claims and evidence through the criteria they expect their students to apply (McNeill and Pimentel 2010). In some situations, teachers can also play a role in comparing and combining the diversity of student arguments to reach a consensus during debate (Chin 2007). Therefore, shifting the classroom discourse requires teachers to shift traditional roles so that they are no longer the sole authoritative voice controlling class discussion but rather adopt multiple roles to foster students to construct and critique knowledge in argumentative practice (Crawford 2000).

Roles of Teacher Questioning for Establishing Dialogic Interaction

Research has suggested that teacher questioning is a major contributing factor shaping the role of teachers for promoting dialogic interaction and students' ownership of learning (Banilower et al. 2013; Chin 2007; Kawalkar and Vijapurkar 2013; Roth 1996; Zhai and Tan 2015). Engle and Conant (2002) suggested that teacher questioning should "encourage students to be authors and producers of knowledge, with ownership over it, rather than mere consumers of it" (p. 404), while Duschl (2008) advocated "the positive gains in learning that come about when the authority for classroom conversation shifts from the teacher to the students" (p. 15). To advance the relationship between students' ownership of ideas and dialogic interaction, Scott et al. (2006) conceptualized a multi-level framework consisting of four communicative approaches created from the compositions of two dimensions (dialogic–authoritative and interactive–non-interactive). While the dialogic approach acknowledges varied ideas to be discussed, the authoritative approach turns attention to only one idea consistent with the goals of the teacher. The interactive approach invites more than one person to participate, but the

non-interactive approach excludes the participation of other people. These two dimensions lead to the combination of four categories of communicative approach. In the dialogic/interactive approach, the teacher investigates students' ideas and considers them equally. In contrast, in the dialogic/non-interactive approach the teacher reviews and synthesizes ideas through listing, comparing, or contrasting similarities and differences. In the authoritative/interactive approach, the teacher focuses on a specific idea and leads students to construct and consolidate that idea through a sequence of questions. In the authoritative/non-interactive approach, the teacher presents a specific idea alone with no student interaction.

Although Scott and other researchers signified the importance of teacher questioning to the development of students' ownership of *ideas* in discussion, some classroom *activities* are still controlled by teachers even if the ownership of discussion ideas belongs to the students (Chin 2007). For instance, in some whole class discussion activities, teachers maintain a position of ownership, but their questions aim to elicit students' prior knowledge about specific concepts and to scaffold a variety of student ideas to reach a consensus without evaluative responses (Roth 1996). In such situations, although the teacher controls the discussion activity, the ideas in the discussion are determined and generated by the students. The teacher's questioning approach in this case is designed to activate students' ideas and compare diverse ideas to determine their weaknesses or strengths and revise them, as well as to guide students to reach a consensus rather than just evaluating the accuracy of their ideas. In contrast, there are cases where activities are maintained by students, but the teacher may serve in the role of a coach to nudge students toward an understanding of canonical science knowledge. In these instances, the ownership of ideas is controlled by the teacher, but the purpose of teacher questions is to challenge and scaffold students to develop fundamental concepts.

These situations demonstrate that dialogic interactions are more complex than a simple ownership of ideas; it is also important to acknowledge the ownership of activities. Thus, the role of teachers' questions should be conceptualized based on both notions of ownership. We re-conceptualized Scott et al.'s multi-level framework to include ownership of both ideas and activities to better reflect the feature and function of teacher questioning in argumentative discourse. The following four categories of dialogic approach emerge:

a. *Teacher's ownership of ideas/ Teacher's ownership of activities* involves the teacher guiding students and directing them to develop ideas and strategies for argument. Teachers control the ideas and activities during dialogue.
b. *Students' ownership of ideas/ Teacher's ownership of activities* involves encouraging students to develop their own ideas through teacher-led dialogue. The teacher only intervenes in recognizing, comparing, and integrating students' ideas to reach consensus. Teachers control the activity, but the direction of dialogue follows students' ideas.
c. *Teacher's ownership of ideas/ Students' ownership of activities* involves the teacher allowing students to conduct activities but challenging students' ideas and resolving their difficulties by asking questions. The teacher guides students' ideas during the students' activities.
d. *Students' ownership of ideas/ Students' ownership of activities* involves the teacher and the students exchanging ideas and developing activities collaboratively through student-led negotiation. Students control their ideas and activities and the teacher is open to learning new concepts.

By analyzing various questioning approaches and the associated teacher–student discourse, we used these four aspects to explicate the critical roles of the teacher in argumentation and to reveal some of the limitations and functions of teacher roles of questioning for establishing dialogic patterns and students' ownership of learning.

Teacher Questions and Student Cognitive Responses

Previous research on the establishment of dialogic interaction has highlighted that teacher questions serve a variety of cognitive conditions (Graesser and Person 1994; Lee and Kinzie 2012; Walshaw and Anthony 2008). For example, Yip (2004) reported ten main types of teacher questions that aim to assess students' higher cognitive skills, such as analysis, evaluation, and synthesis. These questions provide students with cognitive conditions for meaningful learning to resolve discrepant views, connect preconceptions to a new idea, and apply the new idea to novel and realistic situations. Chin (2007) identified four questioning approaches used by science teachers in whole class discussions. These comprised Socratic questioning, semantic tapestry, verbal jigsaw, and framing; each has a different purpose in establishing students' dialogical interactions and understanding. Chin's notion of using different questioning approaches across different conditions to promote student conceptual understanding and cognitive thinking is aligned with Kawalkar and Vijapurkar's (2013) suggestion that teachers use a variety of questions to engage students in argumentative discussion based on the functions and features of the questions. Consequently, different types of questions may have different potential and function to engage students in dialogical interaction and impact various levels of student cognitive responses.

Cognitive educators have advocated the need for teachers to employ more open-ended questioning to promote higher levels of explanations for a specific concept in classroom discussions (Erdogan and Campbell 2008; Mercer and Littleton 2007; Oliveira 2010). Oliveira (2010) found that open-ended questions have more potential to stimulate longer and more articulated student responses, advance higher levels of cognitive thinking at the comprehension level in Bloom's taxonomy (Bloom 1956), and encourage students to clarify their ideas. Palmer (2009) reported that students had higher motivation for science discussion when teachers adopted a more open-ended questioning approach. In a similar vein, Lee and Kinzie (2012) argued that open-ended questions targeting explanation and prediction were more likely to promote students' higher-level cognitive thinking than closed-ended questions aimed at recalling facts.

From a socio-cognitive perspective, teacher questions in argumentation are deemed as socio-cognitive sources which establish the dialectical contexts that scaffold students' efforts to publicly debate differing ideas and reach consensus (Walshaw and Anthony 2008). These dialectical contexts are also known as "interthinking" (Mercer and Littleton 2007), which occurs through the exchange of ideas among teachers and students. As Bailey (2006) explained, "Cognitive development occurs through the accommodation of new ideas into one's existing cognitive framework through social interaction" (p. 232). Engle and Conant (2002) termed this environment a "productive disciplinary engagement" in which students are involved in the social and cognitive process of knowledge construction through dialogic interaction. Engin (2012) found that as teachers adopted various questioning strategies in order to establish a dialectical context, students' dialogic interaction could be deeply prompted and students' reflection on their conceptual understanding was triggered. Similarly, Oliveira (2010) pointed out that students are more engaged in social negotiation and critique of a scientific concept when the teacher posed more open-ended questions.

Despite the effectiveness of using questioning strategies to promote students' cognitive thinking, several researchers have lamented the fact that most early elementary teachers currently do not use them for engaging students in learning (Lee and Grace, 2012; Walsh and Sattes 2005). Wragg and Brown (2001) reported that most early elementary teachers tend to ask questions related to classroom management and factual recall; relatively few questions engaged students' higher-level cognitive thinking. Early elementary teachers may not only lack an understanding of the effectiveness of questioning strategies but also may misinterpret that young children have limited scientific reasoning abilities, communication skills, and the conceptual knowledge necessary to engage in higher-level cognitive thinking (Ahtee et al. 2011).

Although this literature describes forms of questioning and the reasoning they afford, it does not address the shared ownership needed for participant structures that promote knowledge construction and critique, such as argumentation. Much research on classroom discourse has tended simply to focus on the types of teacher questions through the dichotomy of closed- and open-ended questions, rather than on examining the multi-function and relationship between teacher questions and student cognitive responses (Roth 1996). Educators also have suggested that studies should shift the focus from examining the use of teacher questions over a short period of time to longitudinal development across several weeks or months (Martin and Hand 2009; Davis et al. 2006). If we can gain a more nuanced understanding of the relationship between the roles of teacher questioning and students' cognitive responses as well as of how teachers develop various questioning roles over time, teacher education programs including program structures and course assignments focusing on argumentation can be designed effectively and practically.

Methods

This study employed a mixed methods research approach (Creswell 2003) with multiple-case study design to conceptualize the role of teachers' questioning as they attempted to implement the argument-based inquiry approach over the course of 4 years, and to investigate how those changes related student engagement in argumentative processes. While qualitative analysis methods were used to explore the pattern in teachers' development of questioning roles elementary teachers adopt to scaffold students' cognitive responses over time, quantitative measures such as frequencies and statistical analysis were used to explicitly capture the thematic trends of the those changes.

Instructional Context

This multiple-case study was designed as a follow-up study after a 4-year professional development project that emphasized learning science as a negotiation process by embedding arguments in scientific inquiry activities using an argument-based inquiry approach called Science Writing Heuristic (SWH) (Norton-Meier et al. 2008; Chen and Steenhoek 2014). Table 1 provides a description of the five phases of the SWH approach. Given the focus of this study on establishing argumentative discourse in whole class discussion, the third phase is the most relevant to the current discussion.

This project attempted to aid elementary science teachers in designing argument-based inquiry instruction around unit big ideas and provided opportunities for teachers to align

Table 1 Five phases of the SWH approach

Phase I: beginning ideas	Phase II: test/ observation	Phase III: public negotiation (whole class discussion)	Phase IV: reading to compare ideas with experts	Phase V: reflection
Teachers explore students' prior knowledge.	–Students work to design and carry out investigation. –Students organize the data as evidence to support their initial claim.	Students present and debate their group claims and evidence in an attempt to generate a class claim in a whole class setting.	Students compare their arguments to textbooks, the Internet, etc.	Students write down their arguments, incorporating findings and others' ideas, which leads to identifying patterns and big ideas.

learning theory to pedagogical practice. The participating teachers were involved in a 4-year implementation cycle that included 10 days of summer workshop and 3 days of workshop during the school year. The summer workshop was designed around four overarching goals: (1) introducing an SWH approach that connected to National and State Standards, (2) embedding language practices in the SWH approach (e.g., use of argument structure to build science understanding, strategies for writing-to-learn activities, role of multimodal representations in developing understanding), (3) aligning contemporary learning theory and content knowledge to teachers' understanding, and (4) developing pedagogical approaches to implementing the SWH approach (e.g., role of teacher questioning for active dialogical interactions, thinking and talking together as a group activity, ways to play games for the negotiation activity) (see Appendix A for details about professional development workshops on the argument-based inquiry approach). The 3 days of workshop during the school year were designed to meet three goals: (1) sharing teachers' challenges and successes in implementing the SWH approach, (2) supporting teachers' reflection on their implementation of SWH through recording lessons, and (3) supporting teachers in revising their SWH lessons and designing future lesson plans.

The project was conducted in cooperation with 31 elementary teachers and over 750 students across six school districts. Twelve of the teachers taught early elementary grade levels, while the remaining 19 teachers taught upper elementary grade levels. During the 4-year period, only one teacher left the program; this was due to the fact that she moved to another school district. Two professional development liaisons, retired science teachers, observed each teacher's science lessons approximately two times per month to provide feedback directly related to pedagogical practices needed for implementing the SWH approach. Early in the professional development project, it was suggested that each teacher implements at least one unit of SWH in their science classes each year and gradually add more units. Most of the teachers had implemented SWH in their classrooms for all science units after the third year.

Implementing Lessons Using the SWH Approach

Each unit that implemented the SWH approach began with introducing students to the big idea of the unit. The big idea was identified by the teachers based upon State Standards and the National Science Education Standards (NRC 1996) and took into consideration the grade level

being taught. For example, in the third-grade unit on the three phases of water, the big idea was "Water changes state at different temperatures." Once the big idea had been introduced, teachers could ask students to share what they already knew about that big idea. Teaching strategies like concept maps and KWL (what we know-what we want to know-what we learned) charts were usually adopted by teachers during this phase. The purpose of having students discuss their prior knowledge with each other was to help them generate their own research questions for conducting an investigation. After all of the questions had been identified and written on the whiteboard, the teacher guided the entire class to discuss each question in terms of whether it successfully addressed the big idea, whether it was testable in a science classroom, and how it was to be explored. In the unit on the three phases of water, the final research question was "How does ice become water?"

Once a research question had been developed by the class, students designed and conducted their own investigations and subsequently constructed their claims and evidence based on the data gathered form investigations as a group. The teacher would ask penetrating questions during this process that scaffolded students' ability to construct scientific arguments, such as: "What did you observe?" "How would this data/observation relate to your questions?" "What is your claim for the question?" "What evidence can support your claim?" As students developed their claims and evidence as a group, each group was asked to present its argument to the whole class. This public negotiation allowed students to identify the strengths and weaknesses of their arguments. The role of the teachers was to foster students in the argumentative process by modeling the practice of how to question claims and the justifications for those claims. Teachers also took on the role of critiquer to challenge students' ideas and guide their investigations, thereby once again modeling the behavior they expected of their students. Throughout the process, teachers were encouraged to use questioning to engage their students in thinking about conceptual concepts that enabled the construction of knowledge.

After the first round of public negotiation, students returned to their groups to revise their arguments or collect more data to solidify those arguments. These public negotiations could be conducted over multiple rounds until the teacher and students were satisfied with their arguments. The next activity was then to request students to compare their own arguments to what experts say in books or on the Internet. At the end of each unit, each student was required to engage in writing-to-learn activities to reflect on what they had learned and how their ideas had changed compared to the beginning of the unit.

Participants

Due to the focus and the purpose of the study, three teachers were selected from the pool of 31 teachers to analyze in detail based on four criteria: (1) they taught early elementary grade levels, (2) they had no experience with implementing argument-based inquiry in their classrooms before they participated in the project, (3) they had taught science for at least 20 years before participating the project, and (4) they had completed data sources that enabled the researchers to trace their changes over the 4-year period. All of the teachers were female and white. Brielle was a third grade teacher at Roseville Elementary School. Lynette and Susan were second and third grade teachers at Willow Wind Elementary School. Both schools were located in a rural town in the Midwestern United States. For confidentiality, pseudonyms have been used.

Roseville Elementary School served a total population of approximately 220 students. The ethnic diversity of its student population was 98 % White, 1 % Hispanic American, and 1 %

Other. Approximately 45 % of the students in the school qualified for reduced or free lunch. Willow Wind Elementary School served a total population of approximately 200 students. The ethnic diversity of its student population was 97 % White, 1 % African American, 1 % Hispanic American, and 1 % Other. Approximately 27 % of the students attending the school qualified for free or reduced lunch.

Data Collection

The major data sources were 30 science lessons taught by the three teachers over four consecutive years. Those lessons were video-recorded by the three teachers to document when they engaged their students in the third phase of SWH—public negotiation about claims and evidence. Each lesson recorded was 25–45 min in length and focused on whole class discussions after a small group of students presented its written claims and evidence about a concept in science. The total time of Brielle's videotaped classroom observation was 364 min; Lynette's was 280 min; and Susan's was 337 min. The units taught in the three teachers' classrooms were covered by National Standards and State Standards and included units such as plants, force, the three phases of water, sound, etc. Table 2 shows the units taught by each teacher and the length of public negotiation on each unit that was videotaped over the course of the 4 years of this study. Because we were specifically interested in what roles the three early elementary teachers adopted to engage students in debating their claims and evidence in whole class discussions regardless of the unit, those videos allowed us to explore the purpose of the study.

Data Analysis

To triangulate the dynamics of, and changes in, the role of teachers' questioning and the relationships with students' cognitive responses in argumentation, data were analyzed through two approaches: (1) the constant comparative method (Strauss and Corbin 1990), and (2) the enumerative approach (LeCompte and Preissle 1993). In the constant comparative method, the data analysis focused on the identification of similar and different patterns by comparing one segment of data with another. The coding schemes for the analysis of classroom observations were established by the researchers; therefore, the analysis did not utilize pre-existing coding schemes. The enumerative analysis approach was employed to reduce the subjectiveness of qualitative interpretations and to explicitly portray the changes over a 4-year period in teacher use of questioning to promote student cognitive complexities in dialogic interaction. The function of the enumerative approach was to quantify verbal data so as to explicitly capture the patterns emerging from coding schemes. What follows is a description of each approach.

Constant Comparative Method

All 30 classroom observations focusing on whole class discussion were first transcribed, and each transcript was broken into individual utterances. An utterance was defined as a unique idea contributing to the discussion. After identifying utterances, coding schemes were developed to document any potential changes in teacher roles of questioning and the way student responses to teacher and peer questioning over a 4-year period. Codes were assigned for the function utterances served in the text or the meaning or idea they conveyed in the text. For instance, a teacher's question—"That's heat, that's steam, but is it the same thing?" (Brielle,

Table 2 Information about the time and units taught by each teacher and the length of public negotiation on each unit over 4 years

Year/unit Teacher	1st year	2nd year	3rd year	4th year
Brielle (3rd grade)	• Three phases of water (1st semester/ 2 lessons: 95 min)	• Three phases of water (1st semester/ 2 lessons: 88 min)	• Three phases of water (1st semester/ 1 lesson: 42 min) • Planets (2nd semester/ 1 lesson: 35 min)	• Three phases of water (1st semester/ 2 lessons: 49 min) • Planets (2nd semester/ 1 lesson: 31 min) • Environments (2nd semester/ 1 lesson: 24 min)
Lynette (2nd grade)	• Magnets and force (1st semester/ 2 lessons: 71 min)	• Magnets and force (1st semester/ 2 lessons: 65 min)	• Plants (1st semester/ 1 lesson: 40 min) • Sound (2nd semester/ 1 lesson: 38 min)	• Seeds (1st semester/ 1 lesson: 30 min) • Sound (2nd semester/ 2 lessons: 46 min)
Susan (3rd grade)	• Three phases of water (1st semester/ 3 lessons: 107 min)	• Rocks (1st semester/ 2 lessons: 49 min)	• Rocks (1st semester/ 2 lessons: 51 min) • Plants (2nd semester/ 2 lessons: 61 min)	• Rocks (1st semester/ 1 lesson: 37 min) • Plants (2nd semester/ 1 lesson: 32 min)

Note: The amount of time indicates the total time that was spent videotaping that unit

3rd year)—was defined as a single utterance in this context because this question aimed to convey one single meaning that compared the difference/similarity between heat and steam. This utterance was then coded as *compare* (more examples of utterances are provided in Appendices B and C). However, utterances that were not related to the topics were not given any codes, such as "Hey, you gotta erase," or "I am still not done." Similar analysis approaches have been used previously to analyze classroom discussions (e.g., Chen 2011; McNeill and Pimentel 2010; Sampson et al. 2011). Therefore, the total number of utterances analyzed for this study in Brielle, Lynette, and Susan's classrooms were 1480, 1151, and 1474, respectively. Two different coding frameworks were developed to code the utterances in order to address the two research questions, respectively: teacher roles for questioning to address research question 1 and student cognitive responses to address research question 2.

Teacher Roles for Questioning For the analysis of teacher talk and questions, the coding system was established by five graduate students in the field of science education through an interactive process of reviewing the transcripts without utilizing a pre-existing coding system; any disagreements were discussed weekly until a consensus was reached. As a result, the coding system included the following: lecture, guide, recognize, compare, integrate, challenge, elicit, exchange, and encourage. In order to simplify and capture the representation of teacher questioning roles, we attempted to group these nine codes into more comprehensive categories.

Therefore, we conceptualized teacher questioning roles based upon the two conceptions of ownership: ownership of the ideas in discussion and ownership of activities. Figure 1 summarizes the relationship between the two. Based on current literature related to teacher questioning roles (e.g., Chin 2007; Crawford 2000; Kawalkar and Vijapurkar 2013; Walshaw and Anthony 2008), we tried to assign a role to each quadrant in Fig. 1 to explicitly represent and discern the tension between the ownership of ideas and activities. The emergent roles were discussed and refined by the five graduate students. Consequently, four teacher roles were identified as necessary for promoting student argumentation: dispenser, moderator, coach, and

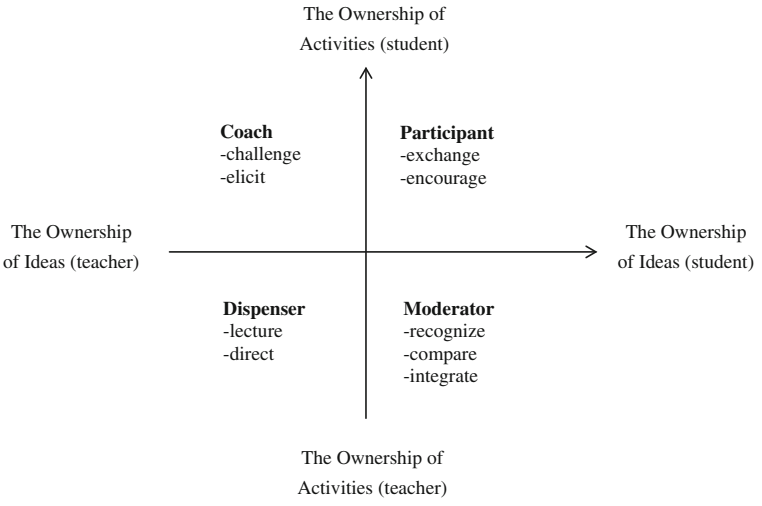

Fig. 1 Framework for teacher roles of questioning from two combinations of ownership of ideas and ownership of activity

participant. For example, a teacher in a dispenser's role controls both the ideas being discussed and the activity; a teacher in a moderator role allows students to control the ideas being discussed during a teacher-directed activity; a teacher in a coaching role controls the ownership of discussion in an activity conducted by students; and a teacher in a participant role allows students to control both the ideas and the activities.

The nine codes were categorized based upon these four roles. As a result, *lecture* and *guide* were categorized as dispenser; *recognize*, *compare*, and *integrate* were categorized as moderator; *challenge* and *elicit* were categorized as coach; and *exchange* and *encourage* were categorized as participant. Appendix B provides a description of the coding scheme and examples of the different codes from classroom transcripts.

Student Cognitive Responses For the analysis of student cognitive responses to teachers or peers, a coding system was established to cover the entire database. Codes developed through the analysis included the following: retrieve, express, elaborate, reframe, defend, synthesize, challenge, and justify. In order to categorize the codes into a hierarchical typology, the codes for cognitive processes were clustered into three levels using Bloom's taxonomy (Bloom 1956). Bloom's taxonomy was employed because it is the most common scheme used for categorizing the levels of cognitive response (Lee and Kinzie 2012; Oliveira 2010). As a result, *retrieve* and *express* were clustered in the low level (knowledge/comprehension); *elaborate* and *reframe* were clustered in the medium level (application/analysis); and *defend*, *synthesize*, *challenge*, and *justify* were clustered in the high level (evaluation). Appendix C presents a description of the coding scheme for student responses and examples.

Enumerative Approach

In order to clearly and explicitly portray the changes over a 4-year period in teacher use of questioning to engage students in argumentation, an enumerative approach was employed to quantify verbal data (LeCompte and Preissle 1993). Once all of the transcriptions were coded based upon the final coding scheme, we calculated the total number and percentages of total utterances for the different coding schemes in each teacher's classroom discussion over 4 years. With the quantified data, chi-square goodness-of-fit analysis was conducted to assess statistical difference in the patterns of the teacher roles for questioning and student cognitive responses over time. This analysis allowed us to document the statistical change in the patterns of teacher roles for questioning and student cognitive responses year by year. The statistical significance was determined at an alpha level of 0.01 for all tests. Non-significant results were not reported.

Findings

RQ1: What roles do early elementary teachers adopt in argumentative discourse, especially in whole class discussion, when they use questioning as a tool to engage students in cognitive response over the course of 4 years?

Teachers increasingly used multiple roles in establishing argumentative discourse as they persistently implemented an argument-based inquiry approach.

Four different roles in establishing patterns of questioning were increasingly adopted by the three teachers over the 4-year period, shown in Fig. 2. In the first year, the most typical role

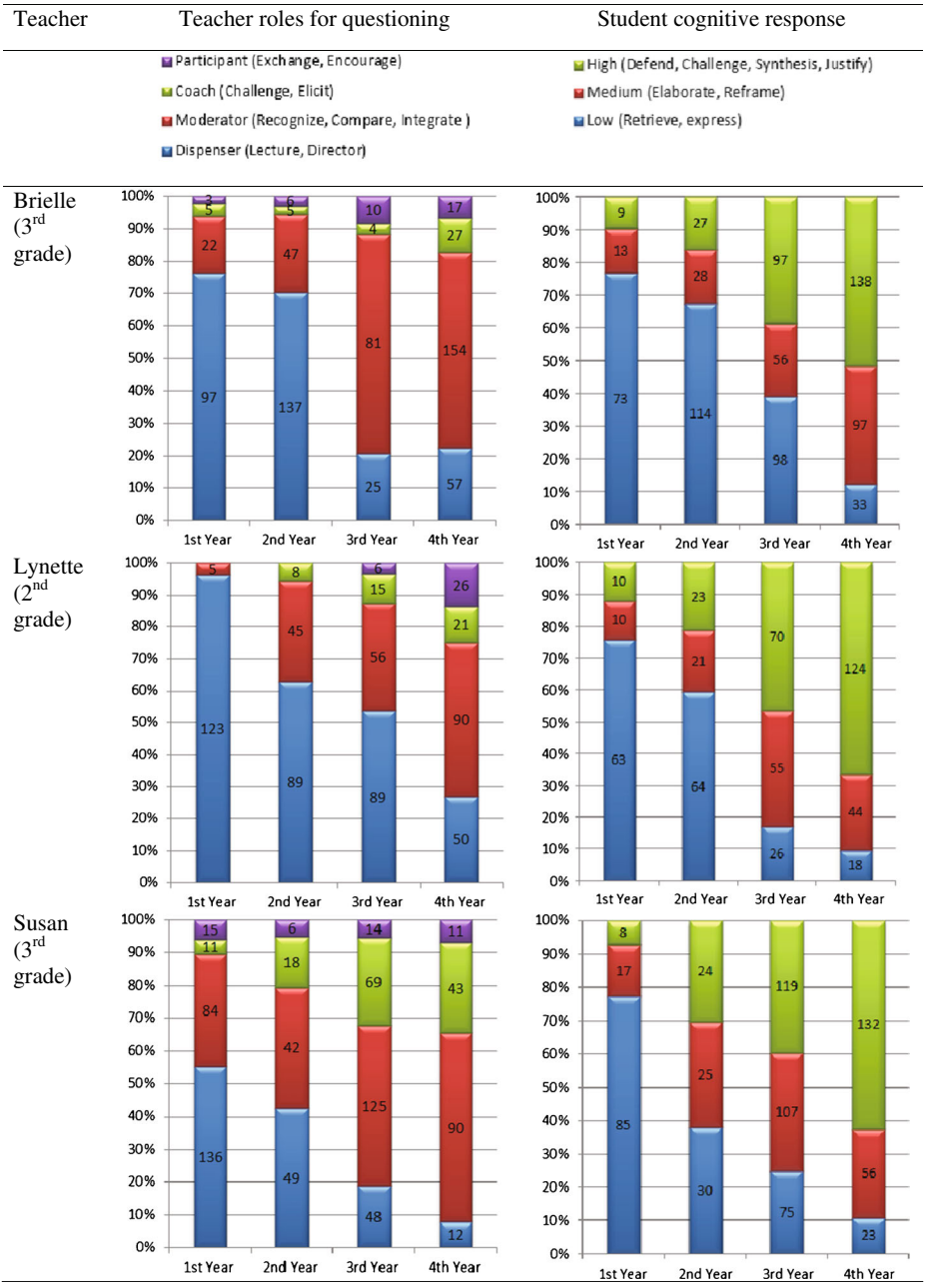

Fig. 2 Number and percentage of teacher roles for questioning used by the three teachers and students' cognitive responses over 4 years

adopted by teachers in classroom discussion was the dispenser, focused on getting a specific response. However, as teachers consistently implemented the argument-based inquiry approach, they developed different roles for questioning in order to establish students' ownership of ideas and activities. The moderator role was one of those first developed for the purpose of

recognizing, comparing, and integrating students' ideas. Taking Brielle as an example, the percentage of utterances coded as moderator increased from 17 % (44/254) in the first year to 60 % (154/255) in the fourth year. Another role developed by the three teachers was that of the coach. For example, the coach role in Susan's class increased from 4 % (44/246) in the first year to 28 % (43/156) in the fourth year. The participant role was another salient strategy that all three teachers developed for argumentative environments. For example, the participant role in Lynette's class increased from 0 % (0/128) in the first year to 14 % (26/187) in the fourth year. Taken together, the findings show a series of shifts in teacher roles for questioning from one single role focused on controlling the ownership of ideas and activities toward multiple roles that provide for students' ownership of ideas and activities.

The chi-square goodness-of-fit test confirmed that the pattern of differences in the aspects were statistically significant over 4 years, except Brielle's class from the first year to the second year (Brielle's class: not significant at the 0.01 level from 1st year to 2nd year; χ^2 (3) = 147.475, $p < 0.01$, from 2nd year to 3rd year; χ^2 (3) = 51.904, $p < 0.01$, from 3rd year to 4th year. Lynette' s class: χ^2 (3) = 360.237, $p < 0.01$ 1st year to 2nd year; χ^2 (3) = 16.18, $p < 0.01$, from 2nd year to 3rd year; χ^2 (3) = 85.009, $p < 0.01$, from 3rd year to 4th year. Susan's class: χ^2 (3) = 29.641, $p < 0.01$ 1st year to 2nd year; χ^2 (3) = 68.127, $p < 0.01$, from 2nd year to 3rd year; χ^2 (3) = 13.857, $p < 0.01$, from 3rd year to 4th year).

RQ2: What are the relationships between the roles teachers adopt and students' cognitive responses?

As teachers used multiple roles in establishing patterns of questioning and framing classroom interactions, higher levels of student cognitive responses were promoted.

The findings show that when these teachers simply adopted the dispenser role for interacting with students, the students mainly engaged in lower-level cognitive activities, such as retrieving scientific vocabulary and providing short answers (see Fig. 2). However, as these teachers adopted multiple roles in framing dialogic interactions, students engaged more in higher levels of cognitive response. The constant comparative analysis shows that while the dispenser role is usually pitched at short answers and lower-level cognition, the moderator, coach, and participant roles usually required much longer student responses to defend, challenge, synthesize, and articulate claims and evidence, and further prompted higher-level cognition.

Taking Brielle as an example, as her questioning patterns shifted away from a single, more teacher-centered role to multiple, student-centered roles, her students' higher-level cognitive thinking grew. Evidence of the shift in students' cognitive response is supported by the increase of their utterances categorized as medium and high, which grew from 14 % (13/95) and 9 % (9/95), respectively, in the first year to 36 % (97/268) and 51 % (138/268) in the fourth year.

The chi-square goodness-of-fit test showed that the pattern differences in the aspects of students' cognitive responses were statistically significant over 4 years as a similar trend as the changes of teachers' roles (Brielle's class: χ^2 (2) = 11.934, $p < 0.01$ from 1st year to 2nd year; χ^2 (2) = 113.891, $p < 0.01$, from 2nd year to 3rd year; χ^2 (2) = 84.206, $p < 0.01$, from 3rd year to 4th year. Lynette' s class: χ^2 (2) = 16.748, $p < 0.01$ 1st year to 2nd year; χ^2 (2) = 116.424, $p < 0.01$, from 2nd year to 3rd year; χ^2 (2) = 29.124, $p < 0.01$, from 3rd year to 4th year. Susan's class: χ^2 (2) = 89.401, $p < 0.01$ 1st year to 2nd year; χ^2 (2) = 23.864, $p < 0.01$, from 2nd year to 3rd year; χ^2 (2) = 47.938, $p < 0.01$, from 3rd year to 4th year). Comparing the chi-square goodness-of-fit results regarding the patterns of teacher roles for questioning and student cognitive response shows that as the patterns of teacher roles for questioning change

statistically, the patterns of students' cognitive response also change statistically. Practically speaking, as teachers increasingly used multiple roles to establish argumentative discourse, they promoted higher levels of students' cognitive thinking.

In the following discussion, several examples will be provided to demonstrate the differences and trends in the four roles of teacher questioning over the 4 years as well as to illustrate how those questioning patterns related to students' cognitive levels of response.

Dispenser The three teachers' dominant role in the first year was dispenser. This role focused on telling the students large quantities of information via direct lecture and on asking students to recall scientific vocabulary, such as "Scientists will have a recipe for doing that. Number one:…" (Lynette, 1st year) or "What does evaporating mean?" (Susan, 1st year). The use of the dispenser role thus usually resulted in short answers from students, such as "Yes" or "Evaporating means to change state" (Susan, 1st year). Such short responses, which are categorized as lower-level cognitive thinking in Bloom's taxonomy, often occurred in the first year of classes. The following example is representative of the use of the dispenser role in directing student discussions when Susan first began to implement the argument-based inquiry approach (see Table 3).

Susan initiates the conversation by asking a direct question to assess whether students have memorized the scientific content she taught in the previous lesson. When Adam fails to recite the answer she is expecting, Susan directly reveals the correct answer ("The matter changes from one state to another state.") and seeks confirmation from the students. She also tries to remind students that they learned about the content in a previous lesson ("I kind of gave it away.") and continuously poses direct questions. During the conversation, Susan uses the personal pronoun "I" or "me" while posing her direct questions or lecturing, thus foregrounding her authoritative status (Oliveira 2010). As a result, her students engaged in

Table 3 Discussion with the teacher as dispenser in the first year

	Classroom discussion	Function of questioning/ teacher role	Student response/ cognition level
Susan:	What have we been studying lately?	Direct/dispenser	
Mary:	Matter.		Retrieve/low
Susan:	Matter. Who can tell me something about matter? Devin?	Direct/dispenser	
Devin:	Um that…solids can turn into liquids, liquids can turn into gas.		Retrieve/low
Susan:	What do I call that when solids change into liquids or when liquids change into gas?	Lecture/dispenser	
Adam:	States.		Retrieve/low
Susan:	It's a state of matter and what's happening to them?	Direct/dispenser	
Adam:	They're…getting heated up.		Express/low
Susan:	Okay, they might be getting heated up. So does the matter change from one state to another state?	Lecture/dispenser	
Class:	Yes.		Express/low
Susan:	Okay, what are the three states or what are the states of matter? I kind of gave it away didn't I? What are the three states? Derek.	Direct/dispenser	
Derek:	Gas, liquid, and solid.		Retrieve/low

Table 4 Discussion with the teacher as moderator in the third year

	Classroom discussion	Function of questioning/ teacher role	Student response/ cognition level
Lynette:	What did you put under that?	Recognize/ moderator	
Lisa:	Ear drum, air particles. Because air particles can get into your ear and get inside your ear drum.		Elaborate/ medium
Lynette:	Okay, when you think about that, that's right. Air particles get inside your ear drum…	Recognize/ moderator	
Sky:	I don't agree with you because I think your ear drum is all closed off and nothing can get in there.		Justify/ high
Lynette:	Anna? Do you agree with Sky?	Compare/ moderator	
Anna:	I don't think it's closed up, so I kind of disagree with Sky, because otherwise you wouldn't really hear what other people are saying.		Justify/ high
Sky:	Okay, I'm kind of confused.		Express/ low
Lynette:	Anna said- at least I think I heard her say- she doesn't think your ear drum is closed up because then you wouldn't be able to hear. Is that what you're saying?	Recognize/ moderator	
Anna:	Yeah. Because if you talk to somebody, and all you see them doing is moving their lips and they're actually talking, then you wouldn't know what they're saying.		Reframe/ high
Lynette:	So what do you think about that Sky? It does to Anna, it does to Kate…. does it make sense to you in some way? Now the question is why does it make sense to you? Does the air particle/ear drum thing make sense to anybody?	Integrate/ moderator	
Sky:	Because I think air particles have to get into a trumpet and your ears, so maybe it would be… we just put it in air particles, and trumpets have to have air to do it or else it will be like…it wouldn't make any sound.		Reframe/ high

teacher-centered activities by retrieving their factual knowledge and providing very short answers.

When adopting the dispenser role, teachers generally use "fill-in-the-blank" questions (e.g., "What do I call that when solids change into liquids or when liquids change into gas?" or "…what are the states of matter?") to evaluate students' factual knowledge rather than utilizing questioning as a means to advance students' conceptual understanding and cognitive thinking. The classroom discourse follows the IRE pattern. In this situation, the students' ideas were isolated and not connected to any previous ideas presented by other students. The high frequency of teacher-directed questions and lecture, in large part, resulted in lower-level forms of student responses.

Moderator As teachers persistently implemented the argument-based inquiry approach, they developed the moderator role to clarify students' ideas and reach a consensus from different individuals. The focus of the moderator role is to recognize, compare, and integrate different ideas from students in the form of a network of relational concepts by posing questions such as "What do you mean the other side of the earth?" (Brielle, 4th year), "Are you in agreement with something they said?" (Lynette, 2nd year), or "That's heat, that's steam, but is it the same thing?" (Brielle, 3rd year). This role functions as a "verbal jigsaw" (Chin 2007) to draw a synthesized picture of a concept. The following example nicely demonstrates how a teacher acted as a moderator in guiding second-grade students in a discussion about sound during the third year of Lynette's implementation of the argument-based approach (see Table 4).

During the conversation, Lynette employs a series of questions focused on recognizing, comparing, and integrating students' understanding to encourage them to evaluate and further build on their understanding of sound. Lynette initiates a question to recognize Lisa's own ideas about the relationship between sound, the eardrums, and air particles. When Lisa starts elaborating her ideas, Lynette poses a confirmation request seeking to clarify what Lisa intended to say. Lynette's confirmation spurs opposing viewpoints from Sky, who believes that the eardrum is completely closed. In response to the two opposing viewpoints, Lynette does not provide her own view or the correct answer. Rather, she invites another student's opinion, which contains a counter-argument and rebuttals ("Otherwise you wouldn't really hear what other people are saying; if you talk to somebody, and…") in the debate. In order to defend her argument, Anna reframes her previous utterance to articulate her justification. After the debate among students, Lynette attempts to integrate the divergent ideas into one consensus that most students might support. Finally, Sky changes his mind and agrees that "Air particles have to get into a trumpet and your ears…." At the end of the discussion, Lynette asks Sky what made him change his mind, and he replies "Anna's explanation made me change."

The discussion in Table 4 demonstrates that adopting the moderator role for questioning elicited divergent responses. Recognizing and comparing questions promoted relatively long student responses and debate. It is important to note that the moderator role is more student-centered than the dispenser role, encouraging students to elaborate, justify, and reframe their arguments, and thus resulting in higher cognitive levels that lead to the construction and critique of counter-arguments and rebuttals. Rather than providing correct answers, Lynette integrated other students' ideas and arguments to foster students to shape more complete scientific concepts at the end of the discussion. The moderator role controls the activities, but students contribute the ideas and arguments to the discussion.

Coach Instead of providing direct corrective feedback or comparison among peers' ideas, in this coach role, teachers challenged students to reflect on their understanding as well as scaffolded them to establish networks among their preconceptions and a new concept, thereby broadening and deepening their conceptual understandings. To illustrate the characteristics of this role, consider the following conversation in which Susan discusses the purpose of roots in her fourth year of implementing the argument-based inquiry approach (see Table 5).

Susan initially uses a series of questions to elicit students' generative ideas about the function of roots. This process of eliciting questions not only focuses on probing students' thinking but zooms in and out of a specific concept generated by the students. For example, Susan uses a broad question ("What might happen to the plant if it didn't have roots? Would it

Table 5 Discussion with the teacher as coach in the fourth year

	Classroom discussion	Function of questioning/ teacher role	Student response/ cognition level
Adam:	If they didn't have roots it would break.		Defend/ high
Susan:	What might happen to the plant then?	Elicit/ coach	
Jake:	Then the plant would probably die.		Elaborate/ medium
Susan:	Okay…could you tell me what's the purpose of the roots?	Challenge/ coach	
Jake:	It's kinda like the heart because if the plant didn't have roots it wouldn't live, and with us, if we didn't have hearts we wouldn't live and stuff, so the plant needs the roots just like we need our heart.		Reframe/ medium
Susan:	And what's the purpose of our heart?	Elicit/ coach	
Jake:	The purpose of our heart is to run blood flows through our body.		Elaborate/ medium
Susan:	If you're saying that the roots are like the heart, which is very important to us, right, and you're saying the roots are very important to the plant, what's the purpose of the roots?	Challenge/ coach	
Jake:	The purpose of the roots is to keep the plant alive, just like the purpose of our heart.		Defend/ high
Susan:	Okay, be specific! How does it keep the plant alive?	Challenge/ coach	
Rose:	Because it sucks up the water.		Defend/ high
Blair:	So one of the purposes, or one of the functions of the roots, is to pull water into the plant. (Susan, the 4th year)		Synthesis/ high

break?") to elicit Jake's generative ideas about the function of the roots and to focus more on a specific question ("What's the purpose of the roots?"). In order to respond to Susan's questions, student Jake not only elaborates but reframes his ideas through self-generated analogical reasoning that compares the roots of a plant to the human heart. This analogical reasoning, which is a core cognitive process of learning science (Kapon and diSessa 2012), did not occur naturally. Rather, it occurred in the discussion because Susan continuously challenged Jack and asked him to clarify his ideas. In other words, Susan's coaching role, which focused on eliciting and challenging, promoted higher-level student thinking and reasoning abilities.

After a verbal exchange between Adam, Jack, and Susan, student Rose jumps into the discussion to help Jack defend his ideas. Student Blair also actively synthesizes Jack's reasoning into a more understandable response. As a result, conceptual understanding was cooperatively constructed as scientific concepts started with the preconceptions and progressively meshed to produce a dialogic outcome.

Unlike the moderator role described previously, the coaching role contributes the teacher's ideas to the discussion but also fosters students to establish their knowledge scheme and extend it. Features of the role as a questioning approach include challenging and eliciting students' ideas, stimulating higher-order thinking such as analogical reasoning, and synthesizing responses.

Participant The three teachers came to adopt the participant role more frequently in the fourth year than they had adopted it before. Two questioning strategies associated with this role included encouraging and exchanging ideas with students. These two strategies created more "space of learning" (Marton and Tsui 2004) for students to debate their arguments with less teacher guidance. The following example is representative of the use of the participant role in discussing the concepts of planet orbits with students in Brielle's fourth year of implementing the argument-based approach (see Table 6).

The interaction continued in this vein, largely among students who directed the discussion and the activity. Students actively discussed their understanding of rotation, orbit, and ellipse as well as further collaboratively constructed the meanings of those vocabularies through verbal exchanges. The role of Brielle in the discussion was to encourage students to elaborate upon and argue with each other's ideas. The participant role thus created more learning space and ownership for students. At the end of

Table 6 Discussion with the teacher as participant in the fourth year

	Classroom discussion	Function of questioning/ teacher role	Student response/ cognition level
Colton:	Well, Logan and I thought that orbit is a path of…		Elaborate/medium
Bill:	Of rotation.		Elaborate/medium
Brielle:	Great! I'm gonna take some notes up here while you're doing that, so I'm going to put path under orbit, okay.	Encourage/participant	
Colton:	And rotation.		Express/low
Logan:	All nine planets take, um, I always forget this word…		Elaborate/medium
Sara:	Ellipse. That's the path they take.		Elaborate/medium
Laura:	So you think the path is called an ellipse? I'm going to put that under orbit.		Judge/high
Erin:	No, no! I thought rotation means going around and orbit was a path, say like last night, people say that Mars is right in front of the sun, the nearest to the sun was Mercury…		Defend/high
Logan	Okay, Mercury, it would cover half the sunlight to, from the moon.		Judge/high
Terrin:	The eclipse, uh, when the sun, you know how the sun gives the moon its light, and then the moon shines its light down, then the earth's shadow blocks the moon.		Reframe/high
Olivia:	I think rotation means like spinning, and orbit means to go around. Ms. Roberts, what do you think? Do you agree with me?		Synthesis/high
Brielle:	Okay. Could I have Olivia show me what you mean by going around? (Brielle, the 4th year)	Exchange/participant	

Ellipses indicate the omission of irrelevant words from one or more sentences.

Table 7 Trend of features of teacher questions and students' cognitive response over 4 years

	Year 1	Years 2 and 3	Year 4
Teacher role of questioning	Single role: teachers focused on dispenser role to lecture and direct classroom discourse. The ownership of ideas and activities controlled by the teachers.	Transition: teachers gradually developed moderator, coach, and participant roles in questioning to promote students' diverse dialogue. The ownership of ideas and activities shifted from the teacher to the students.	Richness: teachers used multiple roles of questioning to support students' thinking and conversation. Students had many opportunities to take ownership of ideas and activities.
Students' cognitive response	Simplicity: students' discourse was restricted to low-level cognition, such as retrieving and expressing ideas.	Transition: students' discourse shifted to medium- and high-level, such as elaborating, reframing, defending challenging, synthesizing, and justifying ideas.	Complexity: students' discourse was in high-level cognition, such as defending, challenging, synthesizing, and justifying ideas.

the excerpt in Table 6, student Olivia even invites Brielle's opinion into the discussion. The students clearly were not afraid of the authority of the teacher, which suggests that they took accountability for the discussion. This situation was not observed in the first 3 years of the study, when teachers took on more teacher-centered roles, like the dispenser. Additionally, the participant role promoted students' higher-order cognition by encouraging them to engage in self-evaluation through judging, defending, and synthesizing their ideas.

Summary of Findings

Table 7 summarizes the findings across the two major features that emerged along the time span involved. The first was that during the 4 years of the study, the teachers increasingly used four roles to establish argumentative discourse; this is referred to as an increasing richness in the teacher role, rather than relying only on the dispenser role as they had in the first year. As the shift to the use of multiple roles occurred, it promoted higher and more complex levels of student cognitive response. The relationship between levels of student cognitive response and teacher roles of questioning is re-conceptualized in Fig. 3. The findings imply that to promote student engagement, teachers should go beyond one single role for questioning and should play multiple roles to tackle different situations by considering student ownership of ideas and activities (Chin 2007; Crawford 2000; Walshaw and Anthony 2008; Zhai and Tan 2015). With the support of teacher questioning, this study suggests that even early elementary students can successfully engage in productively argumentative practices.

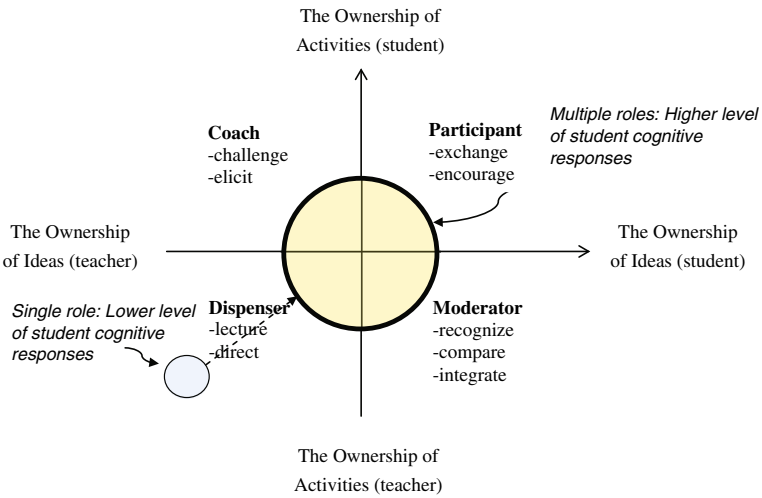

Fig. 3 Relating levels of student cognitive responses to teacher roles of questioning

Discussion and Implications

In this section, we first discuss the conceptualization framework based on the tension between ownership of ideas and activities. We then discuss the connection between teacher questioning and student cognitive responses. Finally, we explore the role of teacher questions in professional development.

Teachers' Questioning for Ownership of Learning

While many studies on the role of teacher questioning have simply dichotomized the types of questions into open/closed-ended and disconnected these two types of questions, the current study conceptualizes four roles of teacher questioning based on the tension between ownership of both ideas and activities to better represent the complexity of argumentative environments. Significant is that the argument-based inquiry approach requires students to engage in dialogic interaction; therefore, the function of the shifting roles of teacher questioning is to fully implement an approach that pushes students to be involved in and take ownership of construction and critique in generating arguments. Although we agree with Scott et al.'s (2006) notion that the roles of teacher questioning should encourage "students to take ownership of the scientific point of view" (p. 617), we also consider that the function of teacher roles may vary across different classroom activities such as teacher-directed instruction and students' discursive activity (Chin 2007; Roth 1996). In this sense, through this conceptual framework, we began to see that the various questions posed by teachers were connected to the four roles, thereby promoting engagement of constructing and critiquing of ideas.

Although the findings of this study show that teachers increasingly developed four roles over the course of the 4 years, the coach role did not occur often in Brielle and Lynette's classes. The participant role also made up a relatively small proportion of the three teachers' classes. These results raised an important question: Why are some roles difficult for teachers to adopt? In terms of the coach role, it is not certain why these two teachers rarely incorporated this role since this goes beyond the purpose of this study. We speculate that it is more challenging for teachers to involve themselves into critiquing students' ideas than constructing ideas with students such as the moderator role. One reasonable explanation from previous studies is that most teachers attempt to investigate students' inadequacy of alternative conceptions but then stop there. They rarely utilize the messages gathered from discussion to critique their students to resolve the discrepancy between existing and new ideas and to resolve that discrepancy (Yip 2004). Tsai and Chang (2005) thus suggested that teachers should design a series of proper "discrepant events" (p. 1093) to elicit conflicts among existing and new ideas. In trying to resolve the conflicts in students' thinking, teachers' questions should use the conflicts as prompts to critique students' ideas and guide them to evaluate the intelligibility and plausibility of a new idea.

Another explanation for the less frequent use of the coaching role comes from Roth's (1996) study reporting that teachers usually want students to feel comfortable;

challenging questions could be potentially threatening for some students and thereby hinder their learning motivation. However, knowledge construction "without appropriate critique would not result in science" (Ford 2008, p. 410). To solve this problem, Kapon and diSessa (2012) suggested analogical reasoning (similar to Table 5) as an optimal questioning strategy that leads to curiosity and is just strong enough to cause students to become dissatisfied with their existing conceptions and willing to engage in seeking changes. Considering the importance of the coaching role, especially in terms of its challenging questions, more research should be conducted on how to develop proper strategies for asking challenging questions for specific concepts and contexts.

Previous studies have shown that it is difficult for teachers to play the role of a participant. Our findings confirm this argument. When teachers played the participant role, they treated their students as experts who complemented the teachers' scientific expertise. As Chin (2007) argued, teachers who are not confident of their own knowledge, especially in elementary school classrooms, might tactically evade or suppress students' questions to elude debatable issues they are not expecting. In addition, teachers may not have or want to spend time listening to what their students want to talk about due to a concern for the accountability pressures they face to teach to high-stakes tests. If we want students to engage in argumentative practices, the participant roles of teacher questions become critical for this form of learning environment.

Teachers' Questioning as a Cognitive Tool

The findings derived from this study indicate that the various roles teachers adopted for questioning not only advanced student ownership of learning but also prompted higher levels of cognitive response. This study thus provides empirical evidence in support of emerging theories on the value of using diverse roles for questioning to prompt students' cognitive responses (Lee and Kinzie 2012; Kawalkar and Vijapurkar 2013; Oliveira 2010).

Although the moderator, coach, and participant roles promoted higher-level cognition in student responses, the three teachers in this study also continued to adopt the dispenser role in the fourth year (Brielle, 22 %; Lynette, 31 %; Susan, 8 %). This finding raises essential questions about whether teachers should eliminate the dispenser role to successfully engage students in argumentative practices. Erdogan and Campbell (2008) pointed out that closed-end questions, similar to the dispenser role in this study, serve important functions such as "focusing" to help students focus on what is important according to the concepts they are learning. Based on the tension between dialogic and authoritative interaction, Scott et al. (2006) argued that teachers should understand when they should play the authoritative role and when they should play a dialogic role in order to continually promote students' cognitive thinking. They stated: "Science is an authoritative discourse which offers a structured view of the world and it is not possible to appropriate the tools of scientific reasoning without guidance and assistance" (p. 622). That is, one single role, even a more student-centered/dialogic role, does not warrant students' engagement in higher-level cognitive thinking. Rather, this process requires that teachers flexibly use different roles—dispenser, moderator, coach, and participant

in this study—to orchestrate classroom discourse. Similarly, Oliveira (2010) suggested that teachers should aim to better understand the important cognitive functions of different questioning strategies and the situations in which they can apply those strategies to help students effectively and productively develop conceptual understandings. More research is needed to determine both the best times and contexts in which to use the different roles in argumentative environments and the most appropriate sequence for using different roles to advance students' conceptual understanding.

Teacher Questioning Roles as Essential Components for Professional Development

The development of different roles to support student argumentation requires time. In this study, it took the three teachers years to shift their classroom environments to a more reform-based model. The importance of this is that changing pedagogy is not a simple matter of developing a new skill or content knowledge; it also requires developing an in-depth understanding of the theoretical orientation (Park and Chen 2012). Davies (2003) claimed that this is difficult to accomplish because "teachers may need to reconsider their long-held beliefs and approaches and ensure the support teachers need through staff development, teacher teams, coursework, and peer-coaching" (p. 23). An increasing body of empirical evidence suggests that it takes more than 18 months before significant shifts in teachers' questioning pedagogy are observed (Martin and Hand 2009; Dori and Herscovitz 2005). While studying an experienced teacher, Martin and Hand (2009) found that the teacher took an 18-month period to move away from a didactic, teacher-centered teaching style to an argumentative orientation in which knowledge is constructed and critiqued through a series of negotiated activities among the teacher and students. Similar findings appear in the work of Dori and Herscovitz (2005), who revealed that teachers took a 3-year cycle to become familiar with the goals of a new curriculum and to develop appropriate roles for instructional practices. Changing pedagogy is not a simple matter of developing a new skill or content knowledge; it also requires developing an in-depth understanding of the theoretical orientation to align pedagogical practices.

Therefore, this study supports Luft's (2001) suggestion that teacher professional development should be designed systematically and should consist of ongoing training (Grigg et al. 2013; Supovitz and Turner 2000). The various roles of teacher questioning should be viewed as an essential component of professional development in order to expedite the shift in teachers' practices from a teacher-centered approach to a more student-centered orientation. Specific types of support would help teachers to integrate multiple questioning strategies into their pedagogy in a specific content and context. Teachers must learn how these roles should be executed and the crucial moments to employ various roles in order to construct meaning and facilitate social negotiation; in other words, the tension between the ownership of ideas and activities. Future studies should continue to analyze the questioning roles and refine such professional development programs to make them even more practical to teachers.

Acknowledgments We wish to acknowledge Mohammad Ahmadibasir, Niphon Chanlen, Brian Pinney, and Ching-Mei Tseng for their intellectual contributions to this work and valuable time on the discussion of the theoretical framework and data analysis.

Appendixes

Appendix A

Table A Descriptions of summer professional development workshops on science writing heuristic (SWH)

	Standards/science content	Learning theory	Language practices	Pedagogical approach
Day 1	• Introduction to National and State Standards -Make connection between standards and SWH approach.	• What is science? -Introduce how scientists develop knowledge through the process of construction and critique.	• Difference between argument and explanation -Look at Walton's ideas.	• Introduction to SWH approach, definition, templates, and five phases.
Day 2 Day 3 Day 4	• Forces and motions -Facilitate teachers to creating a big idea, testable question, and potential investigations based on the big idea. -Guide teacher to construct argument-based lab reports using SWH format and share them across groups to discuss strengths and weakness. -Guide teachers to reflect what they learned and what ideas they developed/ changed through the SWH inquiry.	• What is learning? -Discuss the ideas of learning as meaning-making through negotiation. • What is teaching? -Discuss the ideas of teaching as negotiation through big idea, question, claim, and evidence. • How do student learn science? -Discuss and connect teachers' experience, theoretical perspective based on constructivism, and research reports.	• Introduction to question, claim, evidence framework - Use Mr. Xavier activity (Authors, 2008). • Strategies for writing-to-learn activities -Facilitate teachers understand design writing-to-learning activities through the combination of writing components (e.g., structure, topic, audience, purpose, methods of text production).	• Role of teacher questioning for active dialogical interactions -Examine video clips focused on whole class discussions from high/medium, and low levels of SWH implementation. The foci of examining video clips include: (1) functions and features of questions, (2) students' responses, (3) interaction among teachers and students, and (4) develop big idea through negotiation.
Day 5 Day 6 Day 7	• Human body system -Repeat the procedure of the first unit (forces and motions), but aim to sophisticate teachers' understandings of SWH approach.	• Role of teachers and students in a SWH classroom -Discuss different roles of teachers and students in science classrooms. -Discuss the relationship between the teachers and students in an SWH classroom.	• Role of multimodal representations in developing understanding -Introduce the importance of multimodal representations in science. -Examine the strength and weaknesses of students writing samples from high, medium, low achievement. - Design a writing task to embed multimodal representations.	• Assess students' prior knowledge and understanding through questioning strategies. -Facilitate teachers to design SWH lesson plans through incorporating teacher questioning as a form of assessment into lessons and activities.

Table A (continued)

	Standards/science content	Learning theory	Language practices	Pedagogical approach
Day 8 Day 9 Day 10	• Magnetism and electricity -Repeat the procedure of the first unit (forces and motions), but aim to sophisticate teachers' understandings of SWH approach.	• Creating learning environment that facilitates student science learning in a SWH classroom -Discuss challenge and successes with teachers who are experienced for adopting SWH in science classrooms.	• The relationship between dialogical interaction and writing-to-learn activities - Examine video clips focused on the use of dialogical interaction and writing to build students' understanding toward big ideas from high/medium, and low levels of SWH implementation.	• Thinking and talking together as a group activity -Introduce diverse activities of group discussions through the argument structure of question, claim, and evidence.

Notes: For the second, third, and fourth year, teachers were engaged in (1) science content update, (2) learning theory update, (3) language practices update, and (4) pedagogical approach update.

Appendix B

Table B Four critical roles of teacher questioning to promote student argumentation

Categories	Sub-categories	Description	Examples
Dispenser		-*Feature*: The teacher controls the ownership of discussion and activities -*Function*: The teacher focuses on transforming information, explaining vocabulary, recalling content, and evaluating students' understanding -*Student response*: No response, one-word answer, or one sentence filling in the blank	
	Lecture	-An exposition of a given subject intended to present information and conceptual relationships	-I'll read it to you again, but we're going to shorten it. It says, "As warm water vapor in the air hits the cold glass…"
	Direct	-Any response or instruction used to lead the direction of students' ideas and activities	-I need you to discuss these two words: one of them is orbit and then either rotate or rotation. -Anything else? Anyone want to tell me about matter that we've talked about?

Table B (continued)

Categories	Sub-categories	Description	Examples
Moderator		-*Feature*: Students control the ideas of discussion under the teacher's activity -*Function*: The teacher intervenes in recognizing, comparing, and integrating students' diverse ideas to reach consensus -*Student response*: one or more sentences to explicitly explain ideas or display position	
	Recognize	-Any response used to identify students' ideas or arguments	-Why do you agree with their claim?
	Compare	-Any response used to examine ideas or arguments in order to note similarities and differences	--That's heat, that's steam, but is it the same thing?
	Integrate	-Any response used to synthesize or incorporate students' ideas as a whole	-So what do you think about that Sky? It does to Anna, it does to Kate….does it make sense to you in some way? Now the question is why does it make sense to you? Does the air particle/ear drum thing make sense to anybody?
Coach		-*Feature*: The teacher controls the ownership of discussion in an activity conducted by students -*Function*: The teacher allows students to do the activities but challenges the students' ideas and helps to resolve students' difficulties by asking questions -*Student response*: One or more sentences to explicitly explain ideas and position	
	Challenge	-Any response used to critique students' ideas or arguments	-If you're saying that the roots are like the heart, which is very important to us, right, what's the purpose of the roots? -Why are we comparing? Why not just go on to the socks now?
	Elicit	-Any response used to make students' implicit ideas more explicit	-Are we concerned with how many are in each one, or are we looking? Remember what we were supposed to use our sense of?

Table B (continued)

Categories	Sub-categories	Description	Examples
Participant		-*Feature*: Students control the ownership of discussion and activities -*Function*: Teacher and students exchanging ideas and developing activities collaboratively through student-led negotiation. -*Student response or question*: One or more sentences to construct or evaluate the teacher's ideas	
	-Exchange	-Any response used to share ideas with students	-Wow! How big the owl is. I don't know where the owl perches. Did you find any information? -Do you trust me?
	-Encourage	-Any response used to inspire students' ideas	-You're using a story that we read to help you think about science. That's a good connection.

Appendix C

Table C Coding scheme for student cognitive response

Level	Code	Description	Example
Low	Retrieve	Recall existing information or knowledge to simply respond to teacher's question	-The planet closest to the sun is Mercury. -Solids can turn into liquids, liquids can turn into gas.
	Express	Display idea or feeling without any explanation or reasoning	-No. -It's getting cold.
Medium	Elaborate	Clarify ideas or argument about a concept or task	-Because it's not the same temperature as the room, so the room temperature was hotter, because it has to be thirty two degrees for that to stay ice, and so the fog around it made the ice start to melt, and that made the fog start to melt.
	Reframe	Reconstruct or expand idea based on previous ideas posed by other students or his/herself	-I think he's trying to say that they were born by other planets like something chipped off it and then they all broke up to make one huge planet.

Table C (continued)

Level	Code	Description	Example
High	Defend	Respond to others' questions or challenges to persuade others about his/her ideas	-What I think is the sun does not move; it stays in place, and we just go around and the earth turns and you have daylight and it turns, we have night time, they have daylight. -The reason we chose it for the plain is, if you look at them, these ones are kinda different in a big way 'cause this one only looks like it has kinda marks on it, and these ones all look like they have different things on them. And they all- look at this one and that one- they look different. This one, yeah they're all different.
	Synthesize	Put different ideas together to formulate new ideas	-It's a solid now, but then when it melts, it's a liquid, like right now, and then it'll evaporate, and then it'll be air.
	Challenge	Any response used by an individual to critique others' ideas or arguments	-If Pluto is not a planet then what is it? -It says it evaporates but when it says the evidence, it doesn't give you the information that tells you that's what happened. -You can't do it by color because they are all grey.
	Justify	Provide adequate reasons to evaluate others' ideas or arguments	-No, it's because we touched it so long and the body heat from our hands got into it. -I agree with Brooklyn; when you have the pictures up there of the bowl, the base in the glass it takes the shape of that.

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