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Guiding students towards sensemaking: teacher questions focused on integrating scientific practices with science content

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ABSTRACT

Science education reforms articulate a vision of ambitious science teaching where teachers engage students in sensemaking discussions and emphasise the integration of scientific practices with science content. Learning to teach in this way is complex, and there are few examples of sensemaking discussions in schools where textbook lessons and teacher-directed discussions are the norm. The purpose of this study was to characterise the questioning practices of an experienced teacher who taught a curricular unit enhanced with educative features that emphasised students' engagement in scientific practices integrated with science content. Analyses indicated the teacher asked four types of questions: explication questions, explanation questions, science concept questions, and scientific practice questions, and she used three questioning patterns including: (1) focusing students on scientific practices, which involved a sequence of questions to turn students back to the scientific practice; (2) supporting students in naming observed phenomena, which involved a sequence of questions to help students use scientific language; and (3) guiding students in sensemaking, which involved a sequence of questions to help students learn about scientific practices, describe evidence, and develop explanations. Although many of the discussions in this study were not yet student-centred, they provide an image of a teacher asking specific questions that move students towards reform-oriented instruction. Implications for classroom practice are discussed and recommendations for future research are provided.

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Introduction

Science education reform efforts (ACARA, 2013; NGSS Lead States, 2013; United Kingdom Department for Education, 2014) articulate a new vision of science education where teachers emphasise the integration of science concepts with scientific practices. These reforms were developed, in part, to address the ways that standards and teachers emphasised the separate instruction and assessment of content and scientific practices

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(National Research Council, 2012). By scientific practices, we refer to the work scientists and students do to learn about natural phenomena. Practices require the coordination of knowledge and skill (National Research Council, 2012). A canonical set is developed in the *Framework for K-12 Science Education* (National Research Council, 2012) and includes activity such as planning and carrying out investigations, analysing and interpreting data, and engaging in argument from evidence.

When teaching science content and scientific practices in isolation, scientific practices risk becoming activities and content might be learned through memorisation. It is through integration that students begin to make sense of phenomena in ways that reflect the discourse of science, and it is during sensemaking discussions where teachers and students collectively use scientific practices to develop understandings of phenomena (Berland & Reiser, 2009). Sensemaking is a process where a group works to develop a mutually negotiated understanding of a phenomenon (Weick, 1995). In science education, a sensemaking discussion can involve studying phenomena and using evidence and reasoning to generate scientific knowledge.

We characterise the work of facilitating sensemaking discussions as a form of ambitious teaching (Windschitl, Thompson, Braaten, & Stroupe, 2012). Ambitious teaching is advocated by reformers, but complex to enact on a day-to-day basis in classrooms (Banilower et al., 2013; Crawford, 2000; Kennedy, 2005). Engaging students in sensemaking discussions in science is ambitious for two main reasons. First, in sensemaking discussions, teachers need to use questioning practices that support students to use evidence and reasoning to make sense of phenomena. Here, students develop claims based on evidence (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000) and use the language of science to effectively communicate their ideas (Berland & Reiser, 2009). Second, in sensemaking discussions, the traditional roles of authority and novice are blurred as teachers and students work together to investigate phenomena and co-construct scientific knowledge (Oliveira, 2010b).

Although reforms emphasise that 'engagement in [science] practices … requires students to participate in classroom science discourse' (NGSS Lead States, 2013, p. 3), national studies in the United States have found that sensemaking discussions are rare in classrooms (Banilower et al., 2013). Classroom talk is primarily teacher-dominated, where teachers maintain a position of authority and engage students in textbook-directed lessons (Banilower, Smith, Weiss, & Pasley, 2006; Sykes, Bird, & Kennedy, 2010). The absence of sensemaking discussions in science classrooms suggests that teachers may be unprepared to provide students with these learning opportunities. In particular, teachers may lack clear examples of how to engage their students in sensemaking discussions. Educators who focus on preparing teachers to become effective questioners may not provide explicit supports to help teachers facilitate these interactions (Oliveira, 2010b). They may use ambiguous terms to describe the roles of teachers and students in these discussions. These labels often characterise the student as 'an active inquirer' (Martin, 2006), while the teacher takes on the role of a 'fellow investigator' (Lawson, Abraham, & Renner, 1989) or 'guide' (Martin, 2006). Likewise, teachers may be encouraged to use open-ended questions or probing questions to help students share their own ideas instead of giving the correct answer (Carin, Bass, & Contant, 2005). These descriptions do not help teachers understand how to do the ambitious work of facilitating sensemaking discussions, nor do they challenge teachers' perceptions of their own and their students' roles and relationships in science lessons.

Furthermore, facilitating discussions that emphasise the integration of practices with content is complex. Even experienced teachers may be novices when it comes to engaging students in using scientific practices to construct explanations (Banilower et al., 2013; Windschitl et al., 2012). These methods may be unfamiliar to teachers who learned science in more traditional ways in elementary school (Lortie, 1975). Teachers may not know how to use the scientific practices themselves, so may face challenges in engaging students in this work (Davis, Petish, & Smithey, 2006). Moreover, they may not see their students as capable of generating scientific knowledge (Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999).

To address these issues, science education researchers have designed educative curriculum materials to help teachers learn how to engage students in reform-based science instruction (Davis & Krajcik, 2005). For instance, Davis et al. (2014) designed educative curriculum materials that included narrative descriptions of lessons and examples of rubrics with student work to help teachers anticipate and manage the challenges that students might face in reform-based lessons. In this article, we explore how a curricular unit enhanced with educative features seems to help a teacher facilitate discussions to integrate scientific practices with content in her instruction. The study investigated the following questions:

- What questions does an experienced teacher ask when she teaches a unit that emphasises students' engagement in scientific practices integrated with science content?
- How does an experienced teacher ask questions to engage students in explanation development in whole-class discussions?

Conceptual framework and teacher–student discourse

Vygotsky's (1978) socio-cultural theory of learning suggests that knowledge first develops between people on an interpsychological level and then moves to a learner's mind on an intrapsychological level. This theory emphasises the important role of teacher–student discourse in engaging students in co-constructing knowledge and developing conceptual understanding within a zone of proximal development. In line with a socio-cultural perspective, we argue that teachers' questioning practices can serve as tools to help students process knowledge individually, articulate knowledge collectively, and support one another's learning collaboratively (Kawalkar & Vijapurkar, 2013; Mercer, Wegerif, & Dawes, 1999).

Teachers' questions can establish a learning environment that promotes student learning and collective sensemaking (Erdogan & Campbell, 2008; Lehrer, Carpenter, Schauble, & Putz, 2000). Before engaging students in investigations, questions can help students understand the reasons for using particular scientific practices (Arias, Davis, Marino, Kademian, & Palincsar, 2016; McNeill & Krajcik, 2009). These questions can encourage critical thinking, and move students beyond lower-order thinking questions where they simply recall facts or describe the steps of an experiment (Koufetta-Menicou & Scaife, 2000). As students make sense of their investigations, teachers' questions can help them to use evidence to develop scientific claims. By asking questions such as 'what would happen … ?' or 'how?' teachers can support students to examine different aspects of phenomena and to engage in higher-order thinking (Van Booven, 2015). Engaging students in a 'reflective discourse' enables students to express their own thoughts and beliefs rather than reiterate a textbook explanation (Van Zee & Minstrell, 1997). Similarly, prompting students to use scientific terminology to articulate their ideas can help students develop more sophisticated and scientifically accurate explanations (Chin, 2007). When teachers press students to expand and clarify their thinking, students are able to develop sophisticated reasons and high-quality explanations (Hogan, Nastasi, & Pressley, 1999). These questions can foster a learning environment where students participate in discursive and analytical behaviours that characterise the ways scientists approach their work (Crawford, 2000).

Teachers' questioning routines may also promote more or less authoritative social relationships with students. Students can be positioned as complementary experts when teachers focus on what students say and think, rather than on what the teacher says or thinks is the correct response (Oliveira, 2010a). Student-centred questions encourage individual and social construction of knowledge rather than knowledge reproduction (Jimenez-Aleixandre et al., 2000). On the other hand, classroom talk that focuses on evaluating student knowledge where the teacher initiates, students respond, and the teacher evaluates (Lemke, 1990; Mehan, 1979) reinforces the teacher's authoritative position in the classroom. This pattern of discourse typically emphasises facts and procedures (Lemke, 1990), and it is ubiquitous in science classrooms, even with children as young as preschool (Kleifgen, 1990).

Types of teacher questions

Prior studies on classroom discourse have proposed different types of teacher questions. Many of these studies focus on the specific questions teachers ask including *Bloom's taxonomy* questions (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956), *open and closed question*s (Graesser & Person, 1994), *productive questions* (Elstgeest, 1985), *operational questions* (Alfke, 1974), and *pseudo-questions* (Wellington & Osborne, 2001). For example in elementary science, Oliveira (2010b) identified a set of student-centred questions such as *referential questions* (requests for students to share what they think) and *clarification requests* (students elaborate/clarify previous responses). He also identified teacher-centred questions such as *display questions* (teachers test if students know the right answer) and *comprehension checks* (teachers check if students understand what the teacher said).

Despite the importance of characterising specific questions, single teacher questions are typically not sufficient in supporting student sensemaking (Colley & Windschitl, 2016; Franke et al., 2009). Rather, teachers need to use a series of questions after asking initial questions to help students better understand their own ideas and use of mathematical and scientific practices. Chin (2007) found that when teachers used a sequence of questions, such as *Socratic questioning* (when teachers probe, extend, and elaborate students' ideas) and *verbal jigsaw questions* (when teachers elicit ideas and words to build a collective understanding of scientific terminology), they can scaffold student thinking and help students construct scientific knowledge. In sum, research on teacher questions suggests that identifying specific questions and examining how teachers use those questions is important in understanding the role of teachers' questioning practices in sensemaking discussions. Despite the evidence that sensemaking discussions are both integral to achieving reform-based instruction and challenging for teachers to enact, we know little about how educative supports can scaffold teachers' efforts. This state of affairs calls for the close look at a teacher's practice when she is supported to enact sensemaking discussions where students use scientific practices to develop understandings of phenomena.

Methods

This study uses a qualitative case study approach (Miles, Huberman, & Saldana, 2014) to investigate the ways a fourth-grade elementary teacher, Ms. Jay, uses teacher questions to integrate scientific practices with content during two science units. Building on the work of new reforms (e.g. Australian Curriculum Assessment and Reporting Authority (ACARA), 2013; National Research Council, 2012; United Kingdom Department for Education, 2014), we focused on practices to underscore that learning to engage in scientific investigations involves integrating science content and scientific practices.

This study was a subset of a large-scale quasi-experimental study to investigate the impacts of enhanced curriculum materials on teacher learning, teacher practice, and student learning (Arias et al., 2016; Davis et al., 2014). In the larger study, 50 third-through-fifth-grade elementary teachers were randomly assigned to a treatment (received educative curriculum materials containing educative features) or comparison condition (received original curriculum materials) by school. This study focuses on Ms. Jay, a fourth-grade elementary teacher who had 19 years of teaching experience and a master's degree in teaching with an emphasis in language arts and social studies. Ms. Jay's class consisted of 30 students. Her school was located in an urban-fringe school district in a Midwestern state in the United States, and 60% of the students in the school were eligible for subsidised lunches. Student reading levels ranged from first to fifth grade. Two students in Ms. Jay's class had individualised education plans, and one student was an English language learner. Ms. Jay was selected for this study because she was one of four case study participants who received the curriculum materials with educative features. In addition, her school context and teacher characteristics were similar to the classrooms and teachers in the larger project. Finally, she was interested in discussing her teaching practice and had school administration's support to participate in the research.

Curricular context and design of the educative features

This study centred on the teaching of two *Science and Technology for Children* (STC) kit-based curriculum units: Electric Circuits and Ecosystems (National Science Resources Center, 2004). These STC units were developed with funding from the National Science Foundation and represent strong inquiry-oriented curriculum materials for the elementary grades. They were not designed with the intention of being educative for teachers, nor to reflect the *Next Generation Science Standards* (NGSS Lead States, 2013).

Because these materials pre-dated the *Framework for K-12 Science Education* (National Research Council, 2012) and *NGSS*, as did the design and data collection for this study, as we engaged in research in this project, we focused on a set of practices related to those emphasised in the *Framework*. Furthermore, because our focus was at the elementary level, we zoomed in on some practices that serve as sub-practices within the *Framework*. Some of our focal practices in our curricular design included: designing investigations, making predictions, making observations, using models, analysing and interpreting data, and supporting claims with evidence and reasoning. Designing investigations, making predictions, and making observations can be considered elements of the *Framework's* planning and carrying out investigations, and are critical to supporting young children who are just learning to do this work.

We enhanced the curriculum materials for the treatment teachers by incorporating educative features into both curricular units. Some features foregrounded science practices, some features foregrounded science content, and others integrated both practices and content (Arias et al., 2016; Davis et al., 2014). While we did not explicitly support the teachers' questioning teaching practices, several of the educative features provided exemplars of teachers engaging students in sensemaking discussions, providing rationales for teachers' use of probing questions during whole-class discussions. For example, we included a 'narrative' (Figure 1) of a fictional teacher facilitating a whole-class discussion within the Ecosystems unit. The narrative described a teacher's adaptation of the lesson using effective teaching moves observed in our pilot work, such as probing questions to support student sensemaking. The narratives did not explicitly suggest the types of questions to use to probe student thinking; however, the narratives did provide teachers with rationales describing the importance of allowing students to make sense of scientific phenomena through engagement in scientific discourse. Additionally, we provided teachers a one-page reference guide for facilitating discussions in science (Figure 2). Like the narrative, the reference guide also provided rationales as to why it is important to provide all students with sensemaking opportunities during which students verbalise their thinking and communicate their ideas with others. The reference guide also listed teaching practices teachers could use to support students to engage in scientific discussions. These suggestions included setting expectations for the discussion, allowing wait-time for students to think about their ideas, and encouraging students to ask themselves and others for evidence to support their claims.

Data sources and analysis

Data for this study include video recordings and field notes about Ms. Jay's enactment of the Circuits and Ecosystems units and five teacher interviews. We collected approximately nine hours of video records and associated field notes for nine class periods of instruction (four Circuits and five Ecosystem class periods). We observed the seven lessons because they asked teachers to integrate science content and practices in their instruction, and were also lessons that teachers in our pilot research described as challenging to enact. Table 1 indicates the conceptual and scientific practice goals for each of the seven lessons as described in the lesson curriculum. Lessons were approximately 45 minutes long. Prior to the enactment of each unit, teachers attended a professional development workshop. Two days focused on the Electric Circuits unit and one day focused on the Ecosystems unit. The professional development also introduced teachers to the content and practice supports included in the educative features of the curriculum materials.

To analyse Ms. Jay's teacher questions, we transcribed the videorecords of the lessons and focused on the instances where Ms. Jay engaged in discussions with two or more

Ms. Diaz's Enactment of the Webbing Activity:

Ms. Diaz wanted to make sure the webbing activity was clear and engaging for her students. Since this activity covered complex science ideas, interactions and relationships, Ms. Diaz felt it was important for her students to use observations to provide evidence and examples of interactions and relationships occurring in their small scale ecosystems.

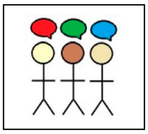
At the beginning of the lesson, Ms. Diaz told her students to make careful observations to look for interactions within their aquaria. After the students shared a few observations they made, Ms. Diaz used the webbing activity to help them make sense of the complexity of their aquaria. She probed each student's idea for evidence from their observations to support their thinking. For example, when Deanna said she saw the elodea being held up by the gravel, Ms. Diaz used dashed blue lines to represent the interaction.

Ms. Diaz then asked if students observed any relationships that were interdependent, where two living things needed each other within the relationship. Students discussed the relationship between the snails and the elodea, stating the snails provided carbon dioxide for the elodea and the elodea provided oxygen for the snail. Ms. Diaz illustrated those connections on the class web using a red line with arrows on each end.

Ms. Diaz asked her students how they could make better sense of their observations they had illustrated on their class web. After some discussion, students decided to make a key for their class web, and labeled the dashed blue line as "interaction" and the red line with arrows on each end as "interdependent relationship." Ms. Diaz asked the students to develop definitions to list in their key. Together, the class decided on the following definition for interdependent relationship: "when two types of living things both need each other to live, they have an interdependent relationship." Ms. Diaz facilitated a similar discussion to aid students in developing a definition for "interaction". The class continued to illustrate their observed interactions and interdependent relationships on their web using the key they created.

Ms. Diaz felt this lesson was helpful in providing her students practice in representing the relationships they were identifying in their aquaria; encouraging students to use their observations as evidence to support their ideas; helping them to understand a key conceptual goal of this unit of study, interdependence; and supporting them to learn about a new graphic organizer – a web – that is very useful to learning science.

Figure 1. Narrative of fictional teacher enacting Lesson 5 Ecosystems unit.



Discussions in Science

Discussions occur in a variety of fields. Science is built upon the practice of communication and collaboration. These **scientific discussions** hold an expectation that statements are supported with evidence. Engaging students in discussions in science allows students to communicate their ideas with the objective of developing scientific understanding. In a classroom discussion, students verbalize their own ideas and provide evidence for those ideas, while being challenged by the ideas of others. This leads to the possibility of expanding and strengthening their own scientific knowledge and the scientific knowledge of their peers.

Why should my students engage in discussions in science?

This is a scientific practice that:

- Enables students to make sense of concepts in science through collaboration
- Makes students' thinking visible
- Helps students learn how to communicate their ideas and findings
- Engages students in productive argumentation by supporting their ideas with evidence
- Helps students learn the social norms of productively interacting with others

How can I help my students engage in discussions in science?

Some strategies include:

- Share with students the expectations for classroom discussions
- Probe students for evidence to support their claims, which should be related to their observations of their tester circuits and the light bulb. Discuss how a lit bulb can serve as evidence for a claim
- Before students observe, tell them that they will be expected to discuss their findings from the investigation, so they are able to think about their claims and determine their evidence before being expected to share their explanations
- Allow students time to think about discussion topics before engaging in the discussion, perhaps do a pre-write to capture some of their ideas
- Model how to productively disagree with differing ideas and help them think about why their ideas might be different
- In this lesson, students may find different results due to problems in the circuits. Have students discuss their varying results and retest their circuits using their troubleshooting skills
- Provide students with stems for comments like "I agree because…" or "I disagree because…"
- Encourage students to ask themselves and others, "How do we know?"

Figure 2. One-page reference guide for facilitating science discussions.

students. We coded adjacency pairs (Sacks, Schegloff, & Jefferson, 1974) or 'Teacher question–student answer' pairs where the teacher makes a discursive move that serves to elicit a student response and is followed by a student discursive move (Oliveira, 2010b). To identify the types of questions asked, we used a combination of open coding and a priori codes derived from literature and the curriculum supports. After checking for agreement on the codes, two researchers coded the video data and checked inter-rater reliability on 20% of the data. An inter-rater reliability of 91% was achieved. The researchers then discussed the coding, code definitions were clarified, and data were recoded as needed.

Table 1. Conceptual and scientific practice goals in lesson curriculum.

Lesson	Overview and conceptual focus	Scientific practice focus
Circuits Lesson 3	Students explore different ways to create a circuit and learn that in a complete circuit electric current travels in a loop that begins and ends with a battery.	Predictions
Circuits Lesson 8	Students construct a light bulb and learn that a resistive component changes electric energy into other forms of energy such as heat and light energy.	Observations Explanations
Circuits Lesson 11	Students build a series and parallel circuit and learn that bulbs and batteries in parallel and series result in circuits with different characteristics.	Predictions Observations Modelling
Ecosystems Lesson 5	Students draw on readings and their observations to discuss that organisms in ecosystems have dependent and interdependent relationships, and living and non-living things have interactions.	Predictions Explanations
Ecosystems Lesson 10	Students design an investigation of the effects of pollution on their small-scale ecosystem using their knowledge of specific pollutants (acid rain, salt, and fertiliser).	Designing Investigations
Ecosystems Lesson 13	Students compare the results of their experiments, learn the importance of controls and averaging data, and infer that water pollution endangers aquatic animals.	Observations Explanations
Ecosystems Lesson 14	Students report on their experiments, pool their data, and develop explanations about the effects of each pollutant, with a focus on the role of producers in an ecosystem.	Predictions Explanations

Data coding and analysis yielded four categories of questioning practices: *explication questions*, *explanation questions*, *science concept questions*, and *scientific practice questions*. As shown in Table 2, *explication questions* provided students with an opportunity to describe their evidence in the form of 'what' happened (Braaten & Windschitl, 2011; Zangori & Forbes, 2013). *Explanation questions* asked students to explain 'why' or 'how' a phenomenon worked. *Science concept questions* guided students to use scientific language to name observed phenomena (e.g. What is this circuit called?). *Scientific practice questions* could support students in developing knowledge and skills in using scientific practices. Based on our emergent coding, the six scientific practices and sub-practices

Table 2. Types of teacher questions.

Questions	Description	Example
Explication question	Questions that may provide students with an opportunity to describe their evidence in the form of 'what' happened in the investigation	What did you see? What happened when you unscrewed the bulb? What did the acid rain do to the terrarium?
Explanation question	Questions that may provide students with an opportunity to explain why or how a phenomenon works and to articulate the causal mechanisms for observed patterns in their observations	How do you know? Why do you say that? Why do you think our compass isn't moving anymore?
Science concept question	Questions that may provide students with an opportunity to use scientific language to name the phenomenon	The battery was touching the wires and the bulb shut off. They couldn't remember what that was called. Who remembers? These kinds of circuits have names. What do you think? Shall I put duckweed under plants or animals?
Scientific practice question	Questions that may provide students with an opportunity to develop knowledge and skills in engaging in scientific practices such as making predictions, recording observations, and developing explanations	What are you going to compare the brightness of the bulb to? What did we say wasn't going to change, so that it would be a fair test? We've collected lots of data, but what does it all mean?

Table 3. Teacher questioning sequences.

Questioning sequences	Description	Example of sequence
Focusing students on scientific practices	Teacher asks a scientific practice question after an explication or explanation question; or asks a series of scientific practice questions to turn students' attention back to the practice	Group one, what did the acid rain do to the terrarium? Why do you think the results are different? Did you have a different formula, or the same formula?
Supporting students in naming observed phenomena	Teacher asks a science concept question after an explication question to help students use scientific language to label observations	What about this circuit, what do you see? These circuits have names, look at the batteries, what do you think?
Guiding students in sensemaking	Teacher asks a scientific practice question, explication question, and then explanation question to help students develop explanations	What was the question before we started our experiment? How did the acid rain affect your terrarium? Knowing what happened, what do you think would happen to the crickets in your ecosystem if it had been polluted?

Ms. Jay emphasised in her questions included: (1) designing investigations; (2) making predictions; (3) recording observations; (4) troubleshooting[1]; (5) using models; and (6) analysing and interpreting data. In this paper, we focus on these practices because they are important elements of planning and carrying out investigations and constructing explanations as described by the *Next Generation Science Standards* (NGSS Lead States, 2013).

After we coded the specific question types, because of the literature that suggests the importance of sequences of questions (e.g. Colley & Windschitl, 2016), we zoomed out a level to look at how the sequence of questioning could support student sensemaking and explanation development. To do this, we noted the series of questions Ms. Jay asked in each lesson. We identified three questioning sequences involving (1) *explication* or *explanation questions* followed by a *scientific practice question*; (2) *explication questions* followed by a *science concept question*; and (3) a series of *scientific practice questions*, *explication questions*, and *explanation questions*. We then looked across the lessons to see if these sequences were consistently used across lessons. Our analysis also let us infer what work each sequence seemed to do in the classroom, and so we developed names for each sequence. Table 3 summarises these questioning patterns.

After coding for question types and question sequences, we coded the interviews with Ms. Jay to understand her rationale for her questioning practices. We used the interviews to triangulate the findings from the observations of Ms. Jay's instruction. We coded the meaning units, or each interview question and response (Miles et al., 2014) related to Ms. Jay's discussion practices. One researcher coded the interview data and a second researcher reviewed the analysis. Table 4 shows the themes that emerged in the interview analysis.

Results

Research question one: teacher questions

Across the nine observed class periods and 389 total questions, Ms. Jay asked four types of questions including *explication questions* (44%), *scientific practice questions* (27%), *explanation questions* (21%), and *science concept questions* (7%) (see Table 5).

Table 4. Themes from Ms. Jay's interviews: Purposes of questions.

Theme	Example from interview transcript
Asking questions to support students' use of practices	Some had a hard time [with] predictions … 'How did you get this? … What did you first think?' (Interview 4)
	They wanted to make up observations in relation to something … 'Just measure it, don't say it's bigger, it's smaller, it grew a lot. What does that mean it grew a lot?' (Interview 4)
Supporting students' speaking and writing in science	First … 'It was a plant,' and now, 'Which is the duckweed?' You have to use [the language] with them and then they pick it up on their own and have a discussion, which is scientific. (Interview 3)
	They're not used to writing or really speaking in science. It was more like we do this activity. You read something and here's your worksheet and then we'll test you at the end. It wasn't … we're going to communicate with the whole class. (Interview 5)
Engaging in collective sensemaking	I was leading the class discussion during the Electricity unit, and then they started leading it in the Ecosystems unit. I would give them something to think about, and then they would make prompts of what they wanted to discuss and what they had to find out. It was almost a debate. (Interview 5)
	At the beginning it was just everyday procedure questions. I think they started thinking more like a scientist and asking questions about their experiments … 'What would happen if we did this instead of this?' I'm like, 'I don't know. What do you think would happen?' Sometimes we actually did it. (Interview 5)

Table 5. Frequency of teacher questions.

Lessons	Explication questions	Explanation questions	Science concept questions	Scientific practice questions	Total questions
Circuits Lesson 3	16 (47%)	5 (15%)	1 (3%)	12 (35%)	34
Circuits Lesson 8	4 (29%)	3 (21%)	1 (7%)	6 (43%)	14
Circuits Lesson 11 Day One	11 (46%)	9 (38%)	1 (4%)	3 (13%)	24
Circuits Lesson 11 Day Two	20 (47%)	4 (9%)	8 (19%)	11 (26%)	43
Ecosystems Lesson 5	26 (33%)	40 (50%)	12 (15%)	2 (3%)	80
Ecosystems Lesson 10 Day One	0	0	0	24 (100%)	24
Ecosystems Lesson 10 Day Two	0	0	1 (3%)	35 (97%)	36
Ecosystems Lesson 13	44 (76%)	2 (3%)	2 (3%)	10 (17%)	58
Ecosystems Lesson 14	51 (67%)	20 (26%)	2 (3%)	3 (4%)	76
Total across class periods	172 (44%)	83 (21%)	28 (7%)	106 (27%)	389

Explication questions

Almost half (44%) of the questions Ms. Jay asked were *explication questions*. These questions encouraged students to share the observations they had made and recorded during the investigation. For instance, Ms. Jay used *explication questions* to elicit students' observations at the end of Circuits Lesson 11 Day Two, which focused on helping students compare the brightness of light bulbs in a series circuit and a parallel circuit.

Student: I had a series [circuit]
Ms. Jay: What happened when you unscrewed the bulb?
Student: The other one turned off.
Ms. Jay: The other one turned off. Okay, anybody else?
Student: I had a parallel circuit.
Ms. Jay: When you unscrewed one bulb?

Student: All the electricity went to the other light bulb.
Ms. Jay: Did it stay on or turn off?
Student: This one that was unscrewed went off, and this one stayed on.

Here, she guided students to consider the differences between a series circuit with two bulbs and a parallel circuit with two bulbs. She asked, 'What happened when you unscrewed the bulb?' to help students notice that when one of two bulbs is unscrewed in a series circuit, both bulbs go out. They also noticed that when one of two bulbs is unscrewed in a parallel circuit, the second bulb remains lit. She did not tell students what they should have seen, but rather elicited their observations and provided an opportunity for students to articulate their sensemaking.

Scientific practice questions

Over a quarter of Ms. Jay's questions were *scientific practice questions* (27%). These questions provided students with an opportunity to develop knowledge and skill in using scientific practices to develop explanations. She used these questions in two main ways. First, she asked scientific practice questions at the beginning of a class period to support students in collecting accurate evidence. Second, she asked the questions in the middle of a discussion to guide students to accurately interpret their data as they developed explanations.

Out of the 106 *scientific practice questions* asked across the 9 class periods, she asked 54 questions that focused on helping students design investigations. All of these questions occurred in the Ecosystems unit, and they focused on helping students learn about the elements of an investigation design. For instance, after two acid rain groups reported different results in the ways the pollutant had impacted their ecosystems, she asked, 'Did you have a different formula, or did you have the same formula? How often did you water?' (Ecosystems Lesson 14). These *scientific practice questions* occurred as students described their investigation findings, and they encouraged them to consider the differences in their investigation design.

Ms. Jay's prediction questions (23 out of 106) guided students to make claims supported by prior knowledge about a scientific phenomenon. In Ecosystems Lesson 10 Day Two she drew on students' experiences baking chocolate chip cookies to prepare them to make predictions about the effect of different pollutants on their ecosystem. She asked,

> What is your prediction with the chocolate chips? … You would pick Hershey's just to eat out of the bag? … Is that what we're testing? … Our prediction needs to relate to our question … Which chocolate chip tastes better in cookies? You need to be using the words for your claim, to begin your sentence.

Ms. Jay used the chocolate chip cookie analogy to help students see that changing the type of chocolate to figure out which cookie tasted the best was similar to changing the amount of pollutant (acid rain, salt, or fertiliser) to investigate the effects pollutants have on ecosystems. These questions emphasised the role of variables (only changing the chocolate) and controls (keeping the remaining cookie ingredients the same) in an experiment and supported students to make predictions about the effects of pollutants as they planned their pollution experiment.

Fewer *scientific practice questions* focused on the practices of observing, modelling, troubleshooting, and analysing and interpreting data. The observation questions (9 out of 106) guided students to make and record accurate observations. The modelling questions (7 out of 106) occurred during the Circuits unit, and they focused on helping students learn to draw and test diagrams of different circuits. The troubleshooting questions (7 out of 106) also occurred during the Circuits lessons and they focused on encouraging students to troubleshoot when they were building and testing their circuits. The analysing and interpreting data questions (6 out of 106) occurred in one lesson, Ecosystems Lesson 13. These questions guided students to look back over their data to notice the ways the pollutant impacted their ecosystem in preparation for the next class period where they would begin to develop explanations.

Explanation questions

Approximately one-fifth of Ms. Jay's questions (21%) were *explanation questions*. These questions often occurred after students had made observations in an investigation. For instance, in Ecosystems Lesson 14, she encouraged students to use their observations to explain what might happen if animals were added to the polluted ecosystems.

Ms. Jay: What would happen in your terrarium if you had crickets and isopods in there, the salt people?
Student: The [salt] will get in the roots of the plants, and the isopods will eat them.
Ms. Jay: If you had crickets … would the crickets survive?
Student: No.
Ms. Jay: Why?
Student: Because there's no food.
Ms. Jay: What about the isopods?
Student: The crickets will eat the poisoned grass, then the poison will go into their bodies and they will die, then the isopods eat the poisoned crickets, and then the isopods die.

Ms. Jay asked *explanation questions* such as, 'Why?' to encourage students to support their claims (why would the crickets die?) with evidence from their investigations (there is insufficient food remaining for the other organisms). The 'poisoned' grass the student referred to was the grass in the terrarium that had been watered with the group's pollutant, salt water. While this student's explanation is not yet scientifically accurate, Ms. Jay's questions are moving students towards a more sophisticated understanding of pollution by pressing them to draw on their evidence to articulate mechanisms for observed patterns.

Science concept questions

Across the nine class periods observed, 7% of Ms. Jay's questions were *science concept questions*. These questions provided students with an opportunity to use scientific language to name and develop an understanding of phenomena. For instance, in Ecosystems Lesson 5, Ms. Jay helped students to develop an understanding of the concepts of interactions, and dependent and interdependent relationships.

Ms. Jay: I want you to think about the definitions of interactions, dependent relationships and interdependent relationships. There are three kinds … that occur … in our mini-ecosystem. What do you think interaction means?
Student: Well, it's something that's needed.
Ms. Jay: Okay. Needed by or used by a living being. That's a good one. Anybody else have another idea what an interaction is?
[*Ms. Jay and students continue to discuss*]
Ms. Jay: Well, it involves one living thing and one non-living thing. For example, the gravel that holds the elodea in place, right? Somebody was mentioning that. Okay, now we've got the living thing is the elodea and the non-living thing is the gravel … Now what about dependent relationships?
Student: Living things can depend on living things.

In this example, Ms. Jay used students' observations to help them learn about important science concepts like interactions between living and non-living things. She referenced the observations students had shared earlier as they worked together to develop an understanding of the concept. Rather than define the concept of interactions at the beginning of the unit, she introduced it in Lesson 5 to enable students to use what they had seen to make sense of the concept.

Research question two: asking questions to engage students in explanation development

Our analysis showed that Ms. Jay consistently used the four question types (*explication questions, explanation questions*, *science concept questions*, and *scientific practice questions*) in three specific questioning sequences to engage students in explanation development. Table 6 shows the questioning sequences she used in each observed lesson.

Focusing students on scientific practices

Ms. Jay asked a series of *scientific practice questions* to *focus students on scientific practices* in all of the nine observed class periods. To illustrate, we first present an excerpt from Ecosystems Lesson 10 Day Two, where she asked 35 out of 36 *scientific practice questions*. Excerpt 1 shows how she asked a series of *scientific practice questions* to focus students' attention on the components of a fair test.

Table 6. Ms. Jay's use of questioning sequences across lessons.

	Circuits unit				Ecosystems unit				
Questioning sequence	Lesson 3	Lesson 8	Lesson 11 Day 1	Lesson 11 Day 2	Lesson 5	Lesson 10 Day 1	Lesson 10 Day 2	Lesson 13	Lesson 14
Focusing students on scientific practices	X	X	X	X	X	X	X	X	X
Supporting students in naming observed phenomena	X	X	X	X	X			X	X
Guiding students in sensemaking	X	X	X	X	X			X	X

Excerpt 1: Ecosystems lesson 10 Day 2

Ms. Jay:	Okay, I want to hear what your [pollution] plan is.	Scientific practice questions: Designing investigations
Student:	Put four teaspoons of vinegar in two litres of water	
Ms. Jay:	You're going to put—dump that whole thing into your ecosystem?	
Student:	No, with the … droppers.	
Ms. Jay:	How much are you going to water?	
Student:	Three times a week.	
Ms. Jay:	What are you looking for? What's the purpose of doing this?	
Student:	We're looking for the roots, and the colour of the ground.	

Ms. Jay used *scientific practice questions* to help students plan how much and how often they would add vinegar (to represent acid rain) to their ecosystem. She then pressed students to restate the purpose of their pollution experiment. These questions turned students' attention back to the practices to focus their thinking on the how and why of using scientific practices to generate knowledge about the impact of pollutants on ecosystems. Ms. Jay's questions prepared students to conduct the pollution experiments in the next lesson.

Another example occurred in Circuits Lesson 3 when she asked a series of *scientific practice questions* to focus students on the practice of making predictions (see Excerpt 2).

Excerpt 2: Circuits lesson 3

Ms. Jay:	Talk with your group about what a prediction is.	Scientific practice questions: Predictions
Student:	A prediction is what you think is going to happen next.	
Ms. Jay:	If I looked outside and said, I think the sky is going to be purple, is that a good prediction? Why?	
Student:	No. Because skies are never purple.	
Ms. Jay:	Because skies are never purple, but do they sometimes rain?	
Student:	I've seen it rain before.	
Ms. Jay:	She's using prior knowledge, stuff that she's already observed to make a prediction.	

Ms. Jay used an example of predicting the weather to support students' understanding that predictions are based on prior knowledge and observations. These questions provided students with an opportunity to learn about predictions and how to make them.

Ms. Jay also engaged in the discourse pattern of focusing students on scientific practices by asking scientific practice questions after explication and explanation questions. As students explained their observations, the scientific practice questions focused their attention on the processes of science informing their results. For example, in Excerpt 3 from Ecosystems Lesson 14, Ms. Jay first asked explication questions to elicit two teams' observations of their terrariums polluted with acid rain. Then she used an explanation question to press the groups to explain the mechanism for their different observations. In the middle of the discussion, she shifted to asking scientific practice questions to remind them about the different variables in their investigations.

Excerpt 3. Ecosystems lesson 14

Ms. Jay:	Where is group one? … What did the acid rain do to the terrarium?	Explication question
Student:	It made less plants.	
Ms. Jay:	The plants were dying? What else did it do?	Explication question
Student:	The soil was hard.	
Ms. Jay:	[to Team Two] Did you feel the soil? Was it hard?	Explication question
Student:	It wasn't hard.	
Ms. Jay:	It wasn't hard, so it was still spongy like before? So, you disagree with this. Did some of your plants die?	Explication question
Student:	No. They're turning yellow.	

[Ms. Jay elicits more observations from the two acid rain teams]

Ms. Jay:	Did you guys use the same exact solutions for acid rain? Why do you think the results are different?	Explanation question
Student:	We watered it more.	
Ms. Jay:	You watered it more? Yours just died and turned yellow.	Explanation question
Student:	We had different formulas.	
Ms. Jay:	Did you have a different formula, or did you have the same formula? You had the same formula, so maybe they were watering theirs more than the other. How often did you water?	Scientific practice question: Designing investigations
Team One:	We watered four times a week.	
Team Two:	We did three.	
Ms. Jay:	You did three. There could be the difference right there.	

Ms. Jay asked *scientific practice questions* to help the groups understand that their results were different because their investigation designs were different. Students realised that they used the same formula of acid rain, but 'watered' their terrarium differently. In order to interpret the different results, they needed to understand the different designs. By asking these questions, students were provided an opportunity to apply what they had learned about fair tests. Ms. Jay's sequence of questions to *focus students on scientific practices* made visible the practices of science and supported students in learning how scientific knowledge develops.

Another example occurred in Circuits Lesson 8 as Ms. Jay guided students to explain their observations and to accurately record their observations. She asked an *explanation question* to encourage their explanations, 'They said our compasses aren't moving anymore, why is that?' After students responded that the circuits were no longer complete, she asked *scientific practice questions* to remind them to draw and label what they had seen, 'The drawing is clear, accurate, complete, but it's not … ? As scientists, we have to be accurate.' Her questions emphasised the integration of scientific practices with science content as students made sense of their observations and learned to record them in an accurate way.

In her interviews, Ms. Jay highlighted her use of scientific practice questions to support student learning. For example, she described a time when students tried to use ideas they had not observed when they developed explanations, '"Well, you didn't see that. We're going to be scientists here. What did you see that leads you to believe this is going to happen?" They wanted to bring in other stuff and not use the experiment' (Interview 4). She emphasised the ways she used questions to make explicit specific practices such as writing evidence-based explanations.

Supporting students in naming observed phenomena

In seven of the nine observed class periods, Ms. Jay used a sequence of questions to *support students in naming observed phenomena*. To illustrate, in Excerpt 4 from Circuits Lesson 11 Day One, she guided students to use a standard circuit to compare the brightness of batteries in a series circuit (Circuit A) and batteries in a parallel circuit (Circuit B). After eliciting students' observations with an *explication question*, she used a *science concept question* to help students use scientific language to identify the different circuits.

Excerpt 4. Circuits lesson 11 day one

Ms. Jay:	What about this circuit, what did you see? (Circuit B is Parallel)	Explication question
Student:	The bulb in Circuit B was dimmer than the standard.	
Ms. Jay:	Anybody else find it dimmer?	Explication question
Student:	It was the same.	
Ms. Jay:	Can I carry this [standard] circuit around for a moment? [To a student] Can you carry your [Circuit B] around for a moment? Here's the standard bulb, how does it look? Compared to [Circuit B]? What do you think?	Explication question
Student:	They are the same.	
Ms. Jay:	These kinds of circuits have names. This one is called series, the batteries are in series. This is a word that you know too. A word that we have used in math before this. And look at these batteries. What do you think?	Science concept question
Student:	Parallel.	

Rather than begin the lesson by defining series and parallel circuits, Ms. Jay provided students with an opportunity to construct and observe the brightness of the two circuits. When one student incorrectly stated that the parallel circuit was dimmer than the standard circuit, Ms. Jay did not evaluate the answer and provide the correct response. Instead, she instructed a student to hold Circuit B, the parallel circuit, and to walk with her around the room while she held the standard circuit. After eliciting students' observations and making certain they noticed the parallel circuit was as bright as the standard circuit, she finally introduced the names of the two circuits. The sequence of questions to *support students in naming observed phenomena* provided students with an opportunity to use the language of science to engage in collective sensemaking.

Another example of this questioning sequence occurred in Ecosystems Lesson 14 as students shared observations of their polluted ecosystems. Ms. Jay asked one team, ‘Fertiliser people, what effects did the fertiliser have on the terrarium?’ After one student responded that there used to be many plants, but now there were few, they were ‘endangered,’ she prompted the class to remember a scientific term they had read about and discussed previously. ‘There is a word that we used yesterday, there’s a few of them, but not so many. Plant life became … ?’ She helped students recall the word ‘scarce’ to enable them to use scientific language to describe their observations.

This theme was also evident in Ms. Jay’s interviews when she said,

> They start talking to each other about it. That’s how I know I am being effective because they can talk to each other about it in the same kind of language, and the same kind of concepts are coming up. (Interview 3)

She underscored the importance of the students, and not just the teacher, using the correct scientific language to discuss their investigations.

Guiding students in sensemaking

Ms. Jay also asked a sequence of questions to *guide students in sensemaking* in seven of the nine observed class periods. Here, she started class with *scientific practice questions*, engaged students in an investigation and asked *explication questions* to elicit their observations, and then used *explanation questions* to guide students to explain the mechanism of their observations. By asking these questions, students were supported in learning how to use evidence and reasoning to make sense of natural phenomena.

Excerpts 5–7 from Ecosystems Lesson 13 illustrate this questioning sequence. Excerpt 5 shows how Ms. Jay first asked *scientific practice questions* to focus students’ attention on the components of an investigation.

Excerpt 5. Ecosystems lesson 13

[10:25]		Scientific practice questions:
Ms. Jay:	You’re going to discuss … the effects of pollutants on your ecosystem, and then you’re going to draw and support conclusions … using the data you’ve collected … Remember, at the very beginning we had a question. What was that question, before we started our experiment?	Designing investigations
Student:	How do you think a pollutant is going to affect it?	
Ms. Jay:	What do you think the pollutants will do to your ecosystem? Each of you had a different variety of question … and then we all made a prediction … Then we talked about control and—what was that other one?	
Student:	Variable.	
Ms. Jay:	Variable. That’s right … then we did the experiment, and we tried to be consistent about the way we watered … We’ve collected lots of data, but now that we’ve collected all the data, what does it all mean?	

Student: Time to put it all together?
Ms. Jay: Time to put it all together … but before we draw some conclusions, we've got to take a better look at our data … Look back at the observations of your team's experiment; find evidence of how the pollutant has affected your team's ecosystem.

Ms. Jay began class by making visible the elements of a scientific investigation. She reminded students about the question they were investigating. She connected the question to the predictions they had made and emphasised the importance of controls and variables. Finally, she guided students to consider the data they had collected.

After the students revisited the scientific practices and before they developed explanations, she used *explication questions* to focus the teams on the observations they had made about their ecosystem (see Excerpt 6).

Excerpt 6. Ecosystems lesson 13

[15:00]		Explication questions
Ms. Jay:	One person from the acid rain group. How did the acid rain affect your … terrarium?	
Student:	We recorded there was a lot of plants, and now there's a little bit less plants.	
Ms. Jay:	Fewer plants. Anything else?	
Student:	Well, the roots are really getting a little black.	
[18:26]		Explication questions
Ms. Jay:	What about the salt people?	
Student:	The roots are all brown and shrivelled up.	
Ms. Jay:	What about this [salt] group?	
Student:	The plants in the terrarium are like, crunchy.	
Ms. Jay:	Crunchy? You mean they're dried up?	
Student:	Yeah, they're dried up.	
[21:55]		Explication questions
Ms. Jay:	What about the fertiliser group?	
Student:	The plants, they were beautiful, and--well, because of the pollutant, now they're a light shade of brown.	
Ms. Jay:	Light brown. You guys have the 10 times the fertiliser, right? Anything else going on with them?	
Student:	A lot of them fell over.	

Ms. Jay asked *explication questions* to elicit the different groups' observations of what happened in the terrarium when they added their specific pollutant (acid rain, salt, or fertiliser) to the small-scale ecosystem. She restated each group's pollutant variable to connect the group's results to their investigation plans. By comparing the results of their investigations, they were afforded an opportunity to apply what they had learned about the importance of using controls and averaging data.

In Excerpt 7, which occurred at the end of the lesson, Ms. Jay asked an *explanation question* to encourage students to use the data they had collected to explain what might happen if animals were living in their polluted ecosystems.

Excerpt 7. Ecosystems lesson 13

[50:00]		Explanation question
Ms. Jay:	Here's a thinking question. Knowing what happened to the plants in the experiment terrarium, what do you think would have happened to the crickets and isopods in your own ecosystem if it had been polluted? Think about your relationships, your dependent and interdependent relationships. What were the first changes you noticed in the terrarium?	
Student:	The pollutant harmed the cricket, but the isopod lived a short time longer because it's going to eat the dead plants, but the dead plants are covered in pollutants, so the isopod would die after they ate the plants.	

Ms. Jay concluded Lesson 13 by asking an *explanation question*, which she labelled as a 'thinking question' for students. She guided students to develop explanations by first referencing the observations they had recorded. Then she emphasised the scientific terminology, dependent and interdependent relationships, to remind them to apply the concepts they had learned throughout the unit. Finally, she prompted students to consider the changes they had noticed in their terrariums over time. These questions afforded students an opportunity to begin to make sense of the pollution investigation and to draw on their evidence to articulate mechanisms for observed patterns. By asking these questions, she called students' attention to the importance of controlling variables, collecting accurate data, and using evidence to support claims about phenomena.

Another example of *guiding students in sensemaking* occurred in Circuits Lesson 11 Day Two when Ms. Jay used the sequence of questions over the class period to prepare students to explain Christmas tree lights as series or parallel circuits. She started the lesson with *scientific practice questions* to remind students to compare their observations of the two circuits to the standard bulb, 'You are going make both of these circuits, and you are going to write down your observations. What are you going to compare the brightness of the bulb to?' After students observed the circuits, she used *explication questions* to elicit their observations, 'I want you to unscrew one of the bulbs. Raise your hand and tell me what happened with the other bulb, but before you do, tell me if you had a series or a parallel circuit.' After students shared observations about the series and parallel circuits, she pulled out a string of Christmas lights. She asked an *explanation question*, 'I've got a question for you. How many of you have these Christmas lights? Are these in parallel or series? How do you know?' By asking these questions, students were provided with an opportunity to use their observations of the series and parallel circuits to explain the mechanism of Christmas tree lights.

In her final interview, she recognised her students' developing practices and their collective sensemaking. She said,

> At the beginning it was just everyday procedure questions. I think they started thinking more like a scientist and asking questions about their experiments … they started, 'What would happen if we did this instead of this?' I'm like, 'I don't know. What do you think would happen?' Sometimes we actually did it. (Interview 5)

She noticed her students were starting to approach their work like scientists and apply their knowledge to imagine new investigations.

Discussion and conclusion

The purpose of this study was to characterise the questioning practices of an experienced teacher who taught a curricular unit enhanced with educative features that emphasised students' engagement in scientific practices integrated with science content. Our analysis indicated that Ms. Jay used four types of questions throughout her science lessons. Almost half (44%) of her questions were *explication questions* where she invited students to describe their observations of phenomena. Around one fourth (27%) of her questions were *scientific practice questions* with one-fifth (21%) focused on *explanation questions*. A small percentage (7%) of her questions were *science concept questions*, which provided students an opportunity to use scientific language to name phenomenon. The findings indicated that Ms. Jay asked these questions in three specific questioning patterns. These involved (1*) focusing students on scientific practices*, a sequence of questions to turn students back to the scientific practice; (2) *supporting students in naming observed phenomena*, a sequence of questions to help students use scientific language to identify observations; and (3) *guiding students in sensemaking*, a sequence of questions to help students learn about scientific practices, describe evidence, and develop explanations.

Although many of the discussions were not yet student-centred, the questioning patterns found in Ms. Jay's lessons offer insights about how teachers can engage students in sensemaking discussions where they integrate scientific practices with content. While there are limitations to using one teacher's enactment to make generalisable claims, her practice provides an image of what is possible, and we focus on what her questioning practices might suggest for teachers and students learning to engage in this complex work.

First, this research adds to previous studies on how teachers can support students' sensemaking of natural phenomena by emphasising the importance of helping students learn how and why to use scientific practices (e.g. Arias et al., 2016; Biggers, Forbes, & Zangori, 2013). This is evident in the ways that Ms. Jay used the questioning sequence of *focusing students on scientific practices* before, during, and after an investigation. For instance, before students planned and carried out their pollution investigations, Ms. Jay spent two class periods and asked 59 of 60 scientific practice questions (Ecosystems Lesson 10 Day One and Two) to help students develop knowledge of how and why to use variables and controls in investigations. Later in Ecosystems Lesson 13 as she asked explanation questions to help the teams make sense of their observations, she reminded students to think back to their pollution design. Similarly, in Circuits Lesson 11, as she asked explication questions to elicit students' observations of the parallel and series circuits, she prompted students to recall the importance of comparing their circuits to the standard circuit to ensure accurate comparisons. Extending prior work that has found teachers may struggle to use scientific practices (e.g. Abell, 2007; Appleton, 2007), this study suggests that teachers' questioning practices can serve as important scaffolds to help students integrate scientific practices with science content.

Second, this study provides examples of questioning practices that encouraged students to develop shared understandings of scientific language, a key component of supporting students' articulation in sensemaking (Berland & Reiser, 2009; Sawyer, 2007). For instance, during the Circuits Lesson 11, Ms. Jay engaged her students in using their observations of series and parallel circuits to collectively characterise the two circuits. Using the questioning sequence of *supporting students in naming observed phenomena* helped the students ground their sensemaking in evidence and supported them in using scientific terminology to articulate their ideas. Providing students with a language for making sense of observations and for developing explanations is critical (Berland & McNeill, 2010; Chin, 2007). This focus on scientific language does not stand alone but becomes one dimension of a teacher's questioning routine to scaffold students' engagement in collective sensemaking (cf. Berland & Reiser, 2009).

Third, this study builds on prior research to suggest that teachers can facilitate productive discussions within a questioning sequence that maintains teacher direction (Chin, 2006; Van Booven, 2015). Although the questioning sequence of *guiding students in sensemaking* was primarily teacher-led, the moves to engage students in the practices of science may have shifted the classroom discourse norms to value collective sensemaking. In her interviews, Ms. Jay mentioned noticing that her students were starting to take on new roles and lead the discussions, work collaboratively to engage in problem solving, and pose their own questions to further the class's explorations (see Table 4). These findings are consistent with other studies that describe the shift in classroom dynamics as teachers position students more as complementary experts and less as novices trying to figure out the correct answer (Berland & Reiser, 2009; Oliveira, 2010b). The questioning patterns may have over time bolstered these students' skills and Ms. Jay's confidence in her students. This is evident in Ecosystems Lesson 13 when Ms. Jay referred to an *explanation question* as a 'thinking question' when she asked students to explain what might happen if crickets and isopods were living in their polluted ecosystem. Labelling the question a 'thinking question' suggests that she recognised its complexity, but saw her students as capable of the intellectual work required to develop an explanation.

Because we made a limited number of classroom observations, we cannot make claims about Ms. Jay's learning or her students' learning, though our larger study shows that participating students developed stronger conceptual understandings of both electric circuits and ecosystems (Smith & Smith, 2014). However, Ms. Jay and her students' movement towards collective sensemaking discussions is evident, and it emphasises the potential of educative curriculum materials in helping teachers and students engage in this work that has been found to be complex and uncommon in classrooms (Arias et al., 2016; Cervetti, Kulikowich, & Bravo, 2015; Davis, Janssen, & van Driel, 2016). Moreover, consistent with prior research, this study suggests that teacher questioning not only supports students' scientific thinking, but it also serves a social function (Oliveira, 2010b). Thus, it is important for teachers to develop linguistic awareness (Oliveira, Sadler, & Suslak, 2007) and become more familiar with the ways that questioning practices establish authority in classrooms. Becoming more aware may help teachers modify their questioning routines and engage students with questions that facilitate sensemaking (Oliveira, 2010b).

Questions continue to be the most common teacher discourse move, and it is important to consider ways to build questions into educative supports. The questioning sequences characterised here may provide guidance for teachers beyond descriptions of merely acting as a 'facilitator' or asking an open-ended question. As this study shows, a more effective approach may be to help teachers learn to use a series of questions that integrate the work of learning about scientific practices, naming phenomena, and using the practices to develop evidence-based explanations of phenomena.

Note

1. While troubleshooting is not explicitly called out in the *Framework* or *NGSS*, this was a practice that Ms. Jay emphasised in her teaching and we see it, too, as being an important part of carrying out investigations.

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