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# Examining Teachers' Instructional Moves Aimed at Developing Students' Ideas and Questions in Learner-Centered Science Classrooms

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**Abstract** Prior research has shown that orchestrating scientific discourse in classrooms is difficult and takes a great deal of effort on the part of teachers. In this study, we examined teachers' instructional moves to elicit and develop students' ideas and questions as they orchestrated discourse with their fifth grade students during a learner-centered environmental biology unit. The unit materials included features meant to support teachers in eliciting and working with students' ideas and questions as a source for student-led investigations. We present three contrasting cases of teachers to highlight evidence that shows teachers' differing strategies for eliciting students' ideas and questions, and for developing their ideas, questions and questioning skills. Results from our cross case analysis provide insight into the ways in which teachers' enactments enabled them to work with students' ideas and questions to help advance learning. Consistent with other studies, we found that teachers could readily elicit ideas and questions but experienced challenges in helping students develop them. Findings suggest a need for more specified supports, such as specific discourse strategies, to help teachers attend to student thinking. We explore implications for curricular tools and discuss a need for more examples of effective discourse moves for use by teachers in orchestrating scientific discourse.

**Keywords** Classroom science discourse · Student questioning · Elementary school science · Instructional practice

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Discourse among scientists is characterized by debate and argumentation based on evidence (Kuhn 1993). In their professional discourse, scientists share their evidence and findings and try to convince their peers through their explanations. Questioning, a central feature of their discourse, is used to clarify and challenge claims and evidence, gain deeper insights, and generate next steps and new directions for inquiry. Accordingly, an essential part of science learning is learning how to engage in key aspects of scientific discourse, including formulating questions, describing mechanisms, and constructing arguments (Lemke 1990; Martin 1989).

The importance of rich productive science talk is highlighted in recent science education reports, most notably the National Research Council's *Taking Science To School* consensus report (National Research Council [NRC] 2007) and drafts of the conceptual framework report for the new science education standards (NRC 2010). Though a centerpiece in science and science education reform, orchestrating scientific discourse in classrooms is difficult and takes considerable teacher effort (Alozie et al. 2010). It requires that teachers have a solid grasp of the science ideas under study as well as some anticipatory sense about how to move students forward in their thinking. It calls for teachers to be comfortable with the uncertainty of the unfolding discourse, open to exploring ideas that arise, able to make judgments about which ideas and questions will be most productive to pursue, and skilled in calibrating their support for students individually and collectively. Perhaps not surprisingly, this form of disciplinary discourse is rare in classrooms. Yet, when teachers do establish norms for productive scientific discourse, studies show that students are more likely to deepen their understanding and develop in their science proficiency (Osborne et al. 2004).

In this article, we report on our study that examined teachers' instructional moves to elicit and develop their fifth grade students' ideas and questions during a learner-centered environmental biology unit. The 12-week unit was designed specifically to help teachers reconfigure their classrooms for science learning in ways that were more learner-centered and more authentic to the discipline and to students' everyday lives. A particular emphasis was placed on creating opportunities for teachers to elicit and work with students' ideas and questions as a source for student-led investigations. A central aim of our study was to gain insight into the ways in which teachers' enactments enabled them to work with students' ideas and questions to help advance learning. To this end, we present three contrasting cases of teachers to highlight evidence that shows teachers' differing strategies for eliciting students' ideas and questions, and for developing ideas, questions and questioning skills.

## Background to the Study

### Learner-Centered Science Instruction

A key design principle of learning environments is that they must be "learner-centered," that is, they must attend to and make use of what students bring to the classroom learning situation (NRC 1999). By eliciting and attending to what students bring, teachers can actively engage students' ideas about, and orientations to, what and how they are learning (Schwartz and Bransford 1998). Moreover, making use of students' contributions in teaching can help transform students' discipline-oriented thinking and ways of participating in disciplinary practices (Baranes et al. 1989).

Teachers who are learner centered in their practice place less emphasis on knowledge transmission and more emphasis on knowledge transformation that entails helping students build on and refine their own knowledge to foster robust learning (Blumenfeld et al. 1997). The primary role of teachers in enacting learner-centered science instruction is to provide students with skilled and thoughtful guidance as they participate in "doing" science in ways similar to the practices of scientists (NRC 2007). This science-as-practice approach (Lehrer and Schauble 2006) places students into the roles of scientists who conduct serious investigations on topics that are relevant to their lives and interests. In such classrooms, students pose questions, design and carry out investigations to pursue those questions, collect and work together to make sense of data, weigh claims and evidence, and share and debate results. Teachers work to ensure that students are purposefully engaging in scientific practices, grappling with important science ideas, and building conceptual understanding through meaningful discourse and activity (NRC 2007). Accordingly, students and teachers participate in a community of practice (Herrenkohl et al. 1999; Magnusson et al. 2004) that emphasizes the characteristic ways of knowing, talking, and doing science (Lemke 1990).

## Classroom Science Discourse

Studies conducted within the framework of science-as-practice suggest that classroom discourse is an essential mechanism for promoting deep understanding and proficiency in science (Herrenkohl and Guerra 1998). By engaging in science talk with one another and their teacher, students become familiar with the specialized ways of participating in science and with how ideas are validated and communicated within the scientific community. Dialogic communication emphasizes making sense through coordination of the ideas and perspectives of classroom members in interaction with one another (Wells and Mejia-Arauz 2006). The course of such conversations cannot easily be predicted ahead of time. In these dialogic interactions, teachers welcome different perspectives and new insights, attend to the intersections between students' everyday ideas and scientific knowledge, and strive to ensure that conversation is directed toward understanding important science ideas and practices (Crawford et al. 2000; Moje et al. 2001).

However, studies of classroom science discourse suggest that orchestrating rich, productive talk is not easy for many teachers. All too often, classroom science talk follows a three-turn Initiation-Response-Evaluation (IRE) sequence in which the initiating question rarely requires a sophisticated response and the evaluation does not encourage students to listen to, or build upon, one another's ideas (Cazden 1988; Lemke 1990; Mehan 1979). This "monologic" form of communication (Bakhtin 1981; Holquist 1990) does not support the discursive goals of learner-centered science, which has as its focus the support of knowledge building by students.

Fostering dialogic communication presents new dilemmas and challenges to teachers. They must decide how to elicit and make good use of the diversity of student ideas; students must be more engaged and willing to make their thinking public as well as listen and respond to the thinking and ideas of their teachers and peers (van Zee et al. 2001). Encouraging students to elaborate on their thinking requires teachers to improvise and respond on the fly to student ideas, and teachers may feel less comfortable opening up discussion on topics they feel less knowledgeable about (Carlsen 1988). Another challenge involves teachers effectively using intersections between students' everyday knowledge and practices and scientific content and practices to advance student understanding (Lee and Buxton 2001). This may be especially daunting for teachers unfamiliar with students' everyday lives, including their cultural norms and practices, and with the norms and practices of science, especially for scientific talk and argumentation. Finally, with the limited instructional time for science in many K–8 classrooms (Marx and Harris 2006), teachers may be hard pressed to spend extended time guiding discussion.

Studies suggest a number of promising starting points for helping teachers make the shift from the typical pattern of talk in classrooms to new forms of discourse that promote productive thinking and participation. For example, academically productive science talk is more likely in classrooms where there are strong, positive norms for supporting claims with evidence (Tabak and Baumgartner 2004). The kinds of questions and questioning practices teachers employ can provoke student thinking and encourage students to generate their own questions to guide inquiry (Beatty et al. 2006; van Zee and Minstrell 1997). Repeated teaching patterns or routines can help teachers and students alike aim discussions toward deeper understanding (Dufresne and Gerace 2004; Herrenkohl and Guerra 1998; Schoenfeld 2002). Specific discourse moves are critical in helping students connect their ideas to one another and bridge everyday and scientific understanding (McNeill and Pimentel 2010; O'Connor and Michaels 1993, 1996; Warren et al. 2001).

## Student Questioning in Science

Formulating and refining questions that can be answered through scientific investigation is a creative act at the heart of scientific activity (Shodell 1995) and a fundamental ability for science proficiency (NRC 1996, 2000). Yet, student questions are rare in classrooms compared with teacher questions (Carlsen 1993; Dillon 1988). Moreover, students often find it challenging to take an ill-formulated question posed at the outset of an inquiry and clarify or refine it to productively guide inquiry (Lehrer et al. 2002; van Zee et al. 2001).

Research on student question generation suggests that teachers' actions are critical (van Zee et al. 2001). When teachers establish discourse patterns that elicit student questions and engage students in discussion about their observations of familiar contexts, more questions are likely to emerge in the science classroom (Penuel et al. 2004; van Zee et al. 2001). In these discussions, teachers' use of wait time and reticence from immediately judging student contributions give space for more student questions to emerge (Gallas 1995; Rowe 1986). Besides observation, other sources of student questions that teachers can tap are prior knowledge, cultural beliefs, information from media, and family experiences (Chin and Chia 2006; King 1994; Reeve and Bell 2009).

Not all student-generated questions can be investigated through classroom-based inquiry, and those that can often require the assistance of the teacher and peers to develop. Some questions students pose can be researched using books or digital resources and are answered readily with reference to facts; others are "wonderment" questions that invite hypothesis generation and prediction (Scardamalia and Bereiter 1992). Teachers can encourage the latter type of questions by engaging students in extended problem-solving activities (Chin et al. 2002) and in student-led investigations (Hofstein et al. 2005). In addition, putting students into collaborative learning situations where they must clarify questions and design investigations together can help develop their questions (Marbach-Ad and Sokolove 2000). Finally, teacher discourse moves such as "re-voicing" that explicitly align different student contributions and ideas with content and set up contrasts among students helps develop questions and provides a motivating context for the development of questions (O'Connor and Michaels 1993).

## The Current Study

The research described here is part of a larger design-based research project led by Shutt, Vye, Bransford, and colleagues (Shutt et al. 2010) that included the creation of an elementary school science inquiry unit to support science instruction that is challenge-based (Schwartz et al. 1999), explicitly leaner-centered (NRC 1999), and authentic in the sense that students engage in tasks that are relevant to the science topic under study and to their own lives and interests. This curricular unit was created via a school-university partnership, subsequently piloted by teachers in the district, and then revised collaboratively with teachers and researchers. The revised unit was then systematically studied as it was being implemented by a cadre of teachers in their elementary classrooms, which exemplifies the tenets of a research-into-practice, practice-into-research approach (Design-Based Research Collective 2003).

Cornerstones of the unit are student choice and student-driven inquiry related to an overarching challenge, all couched in socially interactive group work. In this curriculum unit, titled *Isopod Habitat Challenge* (IHC), students move through phases of inquiry as a means to solve their ultimate challenge—to create an optimum habitat for isopods. Students first share their ideas and questions about isopods, take part in a teacher-guided investigation, and then participate in student-generated investigations to answer their questions. As students move through each phase, they revisit and revise their initial ideas and questions, conduct new research, revise their ideas and reformulate their questions again, and then present their final habitat plan in a public forum.

The unit materials include educative features (Davis and Krajcik 2005) intended to help teachers learn so that they, in turn, can better support student learning. The educative features include overviews of the instructional stance, organization, and phases of the unit; flexible pacing guides that support teacher planning; and embedded notes that signify decision points (i.e., critical junctures) during instruction where it is especially important to attend to student thinking. The lesson materials also include idea generating (e.g., brainstorming) and questioning prompts that are meant to help teachers elicit students' ideas and questions. Materials for students include an *idea journal* for developing and recording ideas and questions and for iteratively investigating key questions as they progress through phases of inquiry, as well as a *team planner* for collaboratively designing the habitat for their isopods. Teachers had access to the unit materials online through the school district website.

University researchers and two teachers who piloted the materials during the unit's early development led three formal professional development sessions to support teachers' learning of how to use the curriculum materials with students. All of these sessions took place after school hours in participating teachers' classrooms. The professional development included instruction on science content, descriptions of lessons and activities, modeling of lessons and activities through video clips, guidance on the pacing of the unit, tips on classroom management, and discussion on effective instructional strategies for teaching science as inquiry. Time was also spent troubleshooting challenges that teachers encountered during unit enactment as well as celebrating and sharing successes. In addition to these formal sessions, the teachers had just-in-time professional development support via email and in-person meetings at school sites with the university researchers who were involved in the unit development.

## Methods

The overarching research question guiding this study was, *In what ways do teachers elicit, re-voice, connect, and/or build upon students' science ideas and questions in the context of enacting the IHC unit?* We were interested in identifying teachers' instructional moves related to elicitation and helping students go further with their ideas and questions. We were particularly interested in documenting interactive "next-step" practices that suggest productive ways to respond to students' thinking.

### Setting and Participants

A total of eight teachers across five elementary schools in one mid-size suburban school district in the Pacific Northwest enacted IHC over 12 weeks in their fifth grade classrooms. We present case studies of three teachers from three different schools in the district. The three teachers, Ms. Holt, Ms. Atwell, and Ms. Lesh (pseudonyms) were purposefully selected as contrasting cases for the present study. Ms. Holt taught at a school whose student population was diverse (24% Asian American, 40% Caucasian, 22% Hispanic, 6% African American, and 8% multi-ethnic), with a high percentage of students receiving free or reduced price lunch (47%). Ms. Atwell's school was predominately Caucasian (60%) and Asian American (19%), with a small percentage of students receiving free or reduced price lunch (13%). Ms. Lesh was at a school that was comprised primarily of Asian

American (52%), Hispanic (19%) and Caucasian (17%) students, with 29% of students receiving free or reduced price lunch.

All three teachers taught in self-contained inclusive fifth grade classrooms. At the time of the study, Ms. Lesh, who had a BA in elementary education, was in her fourth year of teaching and had taught fifth grade exclusively during her career. Ms. Atwell had a BA in English and an MA in teaching, was also in her fourth year of teaching, and had taught fifth grade for all 4 years. Ms. Holt had been teaching at the elementary level for 15 years in the district. During that time, she had taught a range of grade levels (from second to sixth grade) and had spent several years as a teacher in the district's Spanish immersion program. At the time of this study, she was in her second year of teaching fifth grade at her present school. Ms. Holt had a BA in bilingual education and an MA in educational administration.

Within the sample, the three teachers' students represented three different levels of accomplishment with respect to the unit's goals. Students in Ms. Lesh's class had the highest average score on the post-assessment, Ms. Holt's students scored lowest, and Ms. Atwell's students scored in the middle. Preliminary analyses of observation data suggested these three teachers also differed in their approaches to implementing the unit, such that the differences in student results might be analyzed in terms of these differences.

## Procedures

Data sources included narrative documents of lesson enactments produced by integrating field notes and observation protocols completed by classroom observers, as well as semi-structured teacher interviews conducted by researchers during and after teachers' enactment of the unit. The classroom observations were spread across the 12-week unit, enabling observers to visit classrooms and record lessons at the beginning, middle, and end of the unit. We used as the basis for analysis a set of narrative documents from 18 classroom observations across the three teachers. The narratives were comprehensive descriptions of classroom events, targeting teacher and student actions, interactions, and conversations.

For analyzing the narratives, we developed and employed a coding scheme based on discourse interactions, focused particularly on patterns of teacher "uptake" (Nystrand and Gamoran 1991) of student ideas and questions during instruction. The scheme was developed iteratively through a process that entailed creating hypothesis-driven codes, coding evidence of elicitation and uptake, refining the codes, and recoding (Miles and Huberman 1994). Independent coding of narratives was conducted with two coders who met regularly to compare evidence for codes and calibrate their approaches for identifying evidence. Differences were resolved through discussion and consensus. When both coders were uncertain about a piece of evidence, a third researcher provided judgment to help clarify and reach agreement. A brief justification statement was written for each piece of evidence that linked the evidence to a code.

Each teacher was interviewed at two time points: once midway through the unit and at the conclusion of the unit. Specific to the present study, the semi-structured interviews addressed teachers' perspectives on students' experiences, ideas, and questions during instruction, and included questions on what teachers did in response to student contributions. For example, teachers were asked whether and how students' ideas influenced their teaching, the kind of guidance they gave students during student-led research activities, and how they tried to respond to students' problematic ideas. Interviews were audio recorded, transcribed, and then used to further explore developing patterns and themes that emerged from the analyses of narrative data.

### Constructing the Cases

We sought to select cases that, through analysis, could provide guidance to teachers about how to work productively with students' ideas in ways that went beyond simple elicitation. To this end, we took an explanatory, multiple-case study approach (Yin 2003) that focused on explaining variation in individual teacher enactment from curriculum use. In this approach, researchers' aim is not simply to describe the phenomena under study, but to seek explanations for why cases unfold the way they do. Yin's (2003) recommendation is that researchers develop a set of initial possible "rival explanations" for patterns in the data that they expect to find, both as a guide to instrument design and as a method for guarding against confirmation bias.

## Results

We highlight here the evidence from our analyses of teachers' strategies for eliciting students' ideas and questions, as well as strategies for developing ideas, questions and questioning skills. We frame these strategies as *instructional moves*—actions meant to facilitate learning typically through a combination of speech and gesture. *Strategies for eliciting* refer to instructional moves made by teachers in an effort to draw out and make student ideas and questions visible. *Strategies for developing* pertain to the "next-step" instructional moves made by teachers to respond to student thinking. Although we identify and describe the instructional moves separately, we recognize that they are often intertwined during instruction and that teachers typically enact sequences of moves to support learning.

Overall, our findings show that all three teachers were effective in using instructional moves to elicit student ideas and questions. The curriculum materials indicated when teachers were expected to elicit student ideas and questions about isopods and the habitats they prefer, and the three teachers adhered to the curriculum during these occasions. Moreover, their strategies for eliciting were similar. For instance, they all tended to pose open-ended questions meant to invite wonder (e.g., "What would you most like to know about isopods?"), elicit reasoning and anticipatory thinking (e.g., "What do we need to consider in designing our experiment?"), and encourage students to share their investigative experiences (e.g., "What did you find out?").

**Table 1** Teachers' next-step moves and strategies to help students develop their ideas and questions

| Move type | Instructional strategies | Frequency[a] | | |
|---|---|---|---|---|
| | | Ms. Lesh | Ms. Holt | Ms. Atwell |
| Discussing ideas and questions | Discuss students' ideas written in journals | 2 | 2 | 4 |
| | Discuss students' ideas posted on a public chart | 1 | 1 | 7 |
| | Discuss students' questions about isopods/ habitats | 3 | 0 | 8 |
| Revising ideas and questions | Revise students' research questions | 1 | 0 | 5 |
| | Revise students' ideas about isopods/ habitats | 2 | 1 | 3 |
| | Revise students' plans for investigations | 1 | 0 | 5 |
| Reflecting on ideas and questions | Reflect with students on what they have learned | 2 | 2 | 5 |
| | Reflect with students on how they came to know | 1 | 1 | 4 |

[a] The number of class sessions in which a strategy was observed at least once (as tracked in observation protocols). A minimum of six class sessions was observed for each teacher; the sampling of sessions was consistent in terms of phases in the inquiry cycle

Where they differed the most was in their next-step instructional moves and how they worked with students' ideas and questions to help them go deeper in their thinking. Table 1 shows the frequencies of each teacher's move types and strategies for addressing students' ideas and questions over at least six class session observations. Each frequency in the table represents the number of class sessions in which a strategy was observed at least once. As shown, Ms. Holt, whose students scored the lowest on the student assessments, used the fewest different strategies for helping students revisit and revise their ideas and questions. Overall, both Ms. Atwell and Ms. Lesh used more moves and more varied strategies as tracked in observation protocols. Although Ms. Lesh's students scored modestly higher than Ms. Atwell on the assessment, the observation protocol data in Table 1 as well as results from our more detailed analysis of field notes described in the section immediately following show that Ms. Atwell was the most successful of the three teachers in using *strategies for developing* or next-step moves. We return to the discrepancy between the student learning results and observed practices in the discussion, where we attend to the ways that classroom composition can shape patterns of science discourse.

## Strategies for Eliciting Ideas and Questions

All three teachers used the elicitation prompts in the unit materials as well as their own strategies. We identified two common strategies that the teachers used for eliciting students' ideas and questions. One strategy was to ask and invite questions as a means to check for procedural thinking. That is, the teachers asked and invited procedural questions that addressed basic, yet important, information on how to accomplish teacher-structured tasks and how to carry out student-generated investigations. The other shared strategy was to pose open-ended questions that invited wonderment thinking and questions that dealt with hypothesizing and predicting, explaining and clarifying, and making sense of investigative experiences and results.

*Ms. Holt.* Ms. Holt tended to pose questions to elicit students' thinking about the procedural knowledge they would need to carry out activities, such as what materials to use for investigations, the steps to follow, and how to record work. During activities and investigations, she asked questions to check in on students' progress (e.g., "What are you doing?") and to prompt students to think about the sequence of tasks they needed to carry out (e.g., "What will you do next?"). When students experienced difficulties in writing their procedures, she tended to pose elicitation questions to help them move forward in their investigative process (e. g, "How does that help answer your question?").

Ms. Holt also engaged in a regular pattern of inviting students to share their group work experiences and outcomes. She tended to structure these opportunities as whole-class reporting sessions, with students from different investigative groups taking turns stating their group ideas, questions, and findings. Elicitation invitations included such prompts as "What did you research?", "What did you find out?" and "Let's have each group tell us what they did." In the following illustrative excerpt, Ms. Holt asked students to report their findings from an isopod observation as she recorded them on a smart board:

**Student 1:** They live under rocks and in soil.
**Student 2:** When you touch them they roll up…
**Ms. Holt:** Okay….What was the other comment you said?
**Student 2:** They roll up.
**Ms. Holt:** Oh, okay, they roll up.
**Student 3:** They are in different segments.
**Student 4:** They have eyes.
**Student 5:** They don't have eyes!
**Ms. Holt:** There is some disagreement. Let's write them both down for now. If you have any other ideas, please share.

As this excerpt illustrates, Ms. Holt often encouraged students to make public their ideas and findings from investigations. But evidence from our classroom observations showed few elicitation moves for student questions and questioning. Perhaps less surprising, then, was that students rarely asked questions, and the questions they did ask tended to be procedural in nature.

*Ms. Lesh.* To ensure that her students clearly understood how to do tasks and to help them in planning their investigations, Ms. Lesh posed procedural and planning questions. During whole class discussions about planning procedures for investigations, Ms. Lesh tended to invite students to help determine steps and reason through the benefits or drawbacks of following particular steps. For example, while collectively planning an experiment to examine isopods' food preferences, Ms. Lesh elicited students' ideas about the number of isopods needed for the experiment by asking, "How many isopods do we need to be able to answer our question?"

Students then offered their ideas and reasons for various numbers of isopods that should be placed between two foods. One student's response to the elicitation was to select either three or five isopods, "Because if isopods moved in even numbers to both sides, it wouldn't be possible to decide."

When students encountered difficulties during small-group activities and investigations, Ms. Lesh typically elicited their ideas about how to resolve the problem/issue rather than offering an immediate solution. An illustrative example comes from a lesson during which students worked in groups to plan procedures for their student-led investigations. One group was having difficulty determining their procedures, and Ms. Lesh began a brief check-in with the group by eliciting a self-evaluation from them, "Have you figured it out yet?" She followed this by asking the group members to share their procedures. In her feedback, she focused on the comprehensibility and feasibility of the procedures, asking students to think through their steps and provide more specificity but stopping short of telling them what those steps should be.

Ms. Lesh also monitored groups closely, encouraging anticipatory thinking by eliciting students' predictions about what might happen next as they were proceeding through investigations. She tended to ask students while they were working in groups to explain what they were doing and why. In one instance, a student invited Ms. Lesh over to the group's table so that group members could present and garner feedback on their plan to construct a tent for studying the impact of shade on isopod behavior. Ms. Lesh began her conversation with the group by posing a straightforward elicitation question: "Why are you going to make a tent?" This manner of elicitation, in which she used student thinking as a starting point, was characteristic of her teaching during lessons.

*Ms. Atwell.* Ms. Atwell posed questions to elicit students' procedural knowledge for carrying out tasks as well as their ideas for planning and conducting investigations. Similar to Ms. Lesh, she tended to ask students to report out on their designs for student-led investigations and then elicit their reasoning for their design decisions (e.g., "Why did you decide to do it like that?"). She also tended to pose questions to elicit students' ideas about conceptual topics. These questions were typically framed to invite thinking and reasoning (e.g., "What do you think?") and to probe students' grasp of science ideas (e.g., "What is a habitat?"), their ideas about what makes for a good researchable question (e.g., "What does a scientific question involve?"), and the kinds of questions students were working with (e.g., "What is your question?").

During one class session, Ms. Atwell devoted substantial time to engaging students in thinking deeply about the question, "What is a habitat?" She cycled students through three rounds of discussion in which students moved back and forth between small groups and whole-class interactions to consider the question and share perspectives. Only after three episodes of discussion in which the students grappled with this question with each other and with her did Ms. Lesh present a scientific definition for them to discuss. After providing the definition, she then asked students to consider similarities and differences between their ideas and the definition. She brought the discussion to a close by highlighting for them the

**Table 2** Characteristic moves of each teacher

| Ms. Holt | Ms. Lesh | Ms. Atwell |
|---|---|---|
| Structured discussions so that ideas and questions were elicited but fell short on leveraging contributions to help deepen students' thinking | Structured discussions to invite students to share thinking; engaged students directly to help refine ideas and questions; connected their findings and ideas to those of others | Structured discussions to involve students in clarifying their own thinking and exploring others' perspectives |
| When students shared results, posed a question, or raised an issue, tended to acknowledge the contribution and move on | Actively worked with students to ensure that their questions and procedures were feasible | Invited students to help each other think through ideas and questions; encouraged students to ask questions of each other and of her |
| Few observed instances of trying to really work with students on developing their ideas/questions | Tended to try to redirect student thinking through clarification questions and by explaining her interpretation of their ideas | Gave clear feedback when recognizing student thinking; modeled her own thinking when listening to what students were saying |

importance of and value in interpreting a scientific definition in light of what one already knows.

She also elicited conceptual questions from students and structured discussions in a manner that encouraged students to clarify (e.g., "What do you think she [student] means?"), build upon (e.g., "Who can add to what was said?"), or counter one another's ideas (e.g., "Who has a different idea about how we can set this up?"). After investigations, her whole-class elicitations tended to focus on what students learned (e.g., "What did you find out?") as well as what new questions they had (e.g., "What questions do you have now?").

### Strategies for Developing Ideas, Questions and Questioning Skills

All three teachers worked with their students to generate, refine, and pursue questions to frame their investigations and guide their inquiries. Students in all three classes appeared to benefit when the teachers made suggestions and pressed students to clarify and refine their questions and investigations. However, the three teachers differed in their level of attention to students' ideas, questions, and questioning skills during discussions (Table 2).

*Ms. Holt.* Although Ms. Holt often elicited student thinking during whole-class activities and discussions, she rarely provided more than a simple acknowledgement of students' contributions. In very few instances did she try to help students develop their ideas. When she did try, it tended to be in the context of supporting students in designing investigations. In the following excerpt, Ms. Holt tried through her elaborations and questions to support students in thinking about controlling variables in their procedures:

> **Ms. Holt:** So, what materials do you think are necessary to do this investigation or experiment?

**Student 1**: Soil.
**Ms. Holt**: Soil, okay (*writes "soil" on board*). About how much soil do you think is necessary for this?
**Student 1**: A handful.
**Ms. Holt**: Okay, a handful, uh, so, if we just say a handful and we just put it in the runway, how are we going to know if the other side is going to have the same amount, okay? So, what can we do with the soil?
**Student 2**: Use cups.
**Ms. Holt**: Use cups, okay? Okay, so that's important, so we need to keep the amount of soil the same, that's another variable that we need to keep the same.

Another way that Ms. Holt incorporated student thinking into whole-class activities was by having groups report out on their group activities and learning and by asking individual students to share ideas and questions. But when students shared results, posed a question, or raised an issue, she tended to simply acknowledge the contribution and then move on. An excerpt from a discussion about students' plans for conducting their investigations illustrates this. After several minutes of having the students brainstorm ideas in groups about how they might design an experiment to determine the soil type that isopods prefer, Ms. Holt called on each group to report its ideas.

**Student (Group 1):** You should have one soil on one side and the other on the other side and see where they go.
**Ms. Holt:** That's a good start. Next group.
**Student (Group 2):** We sort of thought the same thing, but instead of them [inaudible], a couple of people looked online and found out they like damp soil and I said I don't think you're supposed to do that.
**Ms. Holt:** All right, how about the next group?

This acknowledging but not addressing students' contributions was observed across multiple occasions. When Ms. Holt encouraged groups to express their ideas, the most common responses to a contribution were "next group," "okay," and "So, now we are going to…." In this way, Ms. Holt structured discourse so that ideas and questions were elicited, but she fell short in leveraging those contributions to help deepen students' thinking.

*Ms. Lesh*. Ms. Lesh actively worked with students to ensure their questions and procedures were feasible. She pressed students to refine their questions, often engaging individual students in elaborating on their questions so she could then help tighten them. When telling students to be detailed in their procedures, she often explained that as scientists they "have to be exact" and regularly reminded them to "put in more detail" and "be more specific." When supporting students in refining their research questions, she sometimes re-voiced their questions and then had them elaborate on their questions. For example, when a student wanted to know if isopods sleep during the day or night, Ms. Lesh asked whether the question was really meant to target "day" or perhaps rather "light" and whether the student was interested in knowing about isopod sleep behavior or preference for light. During these interactions, she tended to scrutinize specific word choices in their questions, and her unpacking of their research questions often led students to clarify and make their questions more feasible for investigation.

After group investigations, Ms. Lesh often held whole-class discussions during which students reported their results and described their successes and challenges in carrying out their investigations. When the opportunity arose during these discussions, Ms. Lesh connected student findings and insights to the work of other groups. For example, when a student reported observations that were similar to those of another group, Ms. Lesh made explicit the similarities in findings. When Ms. Lesh took up students' conceptual ideas, researchers observed her to make explicit value judgments about their ideas with supportive comments like "You've got it" and "excellent" and expressed excitement through gestures such as high fives. When students were off the mark in their ideas, she tended to try and redirect their thinking through clarification questions (e.g., "Are you really asking about day or are you interested in light versus dark?"), and explaining her interpretation of their ideas. In this manner, Ms. Lesh was observed to do much of the conceptual lifting during discussions, taking an active role in explicating ideas, identifying connections, highlighting key science ideas, and leading the knowledge building.

*Ms. Atwell.* As did Ms. Lesh, Ms. Atwell worked continuously with students to help them learn how to ask researchable questions. For example, Ms. Atwell helped a student refine his question by implicitly making the point that the process of developing a researchable question begins with what one already knows.

**Student:** What kind of bugs do they eat?
**Ms. Atwell:** Do we know that isopods eat bugs?
**Student**: No.
**Ms. Atwell:** How can we re-phrase the question?
**Student:** Do they eat bugs? What are their predators [prey]?
**Ms. Atwell:** (*To class*) I know from walking around that these questions overlap with others in a lot of groups. Wiggle your fingers if this overlaps with your list (*Lots of students raise their hands and wiggle their fingers*). Good.

Another time, Ms. Atwell engaged students in a whole class sharing and discussion of their initial research questions. During this discussion, she posed a clarification question as a first step toward helping a student refine a research question and also used the conversation to model for the class what she was thinking when listening to what students were saying.

**Student:** What does the climate need to be for them [isopods]?
**Ms. Atwell:** What do you mean by climate?
[pause]
**Ms. Atwell:** *(to whole class)* What I'm trying to do is paraphrase in my mind what I think she's saying. It's a good thing for you to do when you're listening, too.
**Ms. Atwell:** *(to student)* We have temperature questions (*referring to list of student-generated research questions*), but it seems like you're going a little further.

**Student:** Does the isopod's habitat need to be hot and dry or cold and moist? (*Ms. Atwell records the student's question on poster paper.*)

When Ms. Atwell held inquiry discussions, she often structured them to involve students in clarifying their own ideas and questions and exploring others' perspectives. She also invited students to help each other think through their ideas and questions. For example, when a student shared her prediction about isopods' preferences for location, Ms. Atwell asked, "Does anyone want to respond?" She then invited students to ask clarification questions about the prediction and encouraged them to provide reasons why they did or did not think that it would hold true. In this way, she established a discourse environment in which students could be co-participants in the task of sense making and knowledge building.

Ms. Atwell, similar in approach to Ms. Holt and Ms. Lesh, asked groups to report out their designs for their student-led investigations and, once investigations were conducted, encouraged them to report their findings. One notable difference was that Ms. Atwell often encouraged the students to ask questions, and she gave clear feedback on their thinking. For example, when a student group was describing the reasoning for their second research design, both Ms. Atwell and a student engaged the group.

**Student 1 (G1)**: Since in the first investigation they [isopods] liked the moist side… (*student references the group's findings from their first investigation*)
**Ms. Atwell:** Good thinking. I like how you built on knowledge you already had.
**Student 2**: I have a question. Why did you decide to do it like that?
**Student 1 (G1)**: We wanted to have it super light and super dark on each side.
**Ms. Atwell:** So, were you thinking if you had more contrast you might get better data?
**G1:** Yes (*multiple students from group respond*).
**Ms. Atwell:** Thanks, team.

As evident in this excerpt, Ms. Atwell shared responsibility for advancing the class' collective understanding with her students. Additional evidence from our observations illustrated that she encouraged students to question each other, to engage in argumentation about ideas, and to participate in knowledge building to help advance individual and collective understanding.

Ms. Atwell also used re-voicing as a way to clarify her own understanding of student thinking and to encourage students to put scientific terms in their own language to check for understanding. For example, during one class session she asked a student, "So how would you answer, 'What is a habitat?'" She listened to the response and then followed with, "I am going to paraphrase what you are saying, and let me know if that's what you're saying." After confirming the paraphrasing with the student, Ms. Atwell asked, "Can you put that back in your own words for me so I can put it down?" After the student gave an answer, she recorded, "A place where an animal can survive and be healthy."

## Discussion and Conclusions

Our comparative case studies revealed that the three teachers differed in the ways they developed or took up student questions posed in investigations in ways that may help explain observed differences in student learning across classrooms. Ms. Holt, whose students scored lowest on a test of their skill in posing investigable questions, made fewer moves to help develop students' initial ideas and questions for investigation than did the other teachers. In the two other classrooms, where students performed better on the assessment, the teachers used multiple strategies for developing their initial questions. Even when implementing the same curriculum unit, which provided explicit guidance about how to elicit questions and called for multiple iterations in students' design of investigations, significant variation was observed in how teachers took up student ideas to help them develop their skill in posing investigable questions.

The finding that some teachers could readily elicit questions but not necessarily help students develop them is consistent with other studies that have provided tools to help teachers elicit and attend to student questions and thinking. An earlier study by Yarnall et al. (2006), for example, revealed that teachers readily adopted handheld software tools designed to elicit and aggregate student topics in advance of instruction, but how often they used the tools varied depending on whether they considered attending to student thinking an important goal for assessment. Thompson et al. (2009) have developed a hypothetical learning progression for early career science educators focused on ambitious pedagogical practices. One such practice they have outlined and studied is "working with student ideas." In a study of 13 early-career educators, the team found that many teachers were able to elicit students' initial hypotheses, questions, or thinking about scientific phenomena by their first year of teaching, but only four regularly referenced those ideas in class and adapted their instruction in response to student thinking (Thompson et al. 2010).

Each of these studies and our own point to both the power and potential limitations of curricular tools for helping teachers attend to student thinking. Strikingly, all three teachers (as well as others we observed in this study) were able to use the curricular guidance in the materials to elicit student questions. The teachers in interview data, not reported here, all found this aspect easy and compelling to enact. Likewise, the teachers in Yarnall and colleagues' study were readily able to adopt the handheld software (Yarnall et al. 2006), and teachers in Thompson and colleagues' study employed an *Eliciting Tool* (Thompson et al. 2009) developed specifically to help teachers attend to student thinking. But sometimes, teachers in our study were not always able to develop students' questions and ideas because, as we report elsewhere (Phillips et al. 2010), they had to balance time considerations with the need to give students multiple opportunities to develop their thinking. In the other two studies, teachers' goals were important filters in whether they developed student thinking. Those teachers for whom attending to student thinking was a top goal were readily able not only to adopt tools and routines but also to adapt them to student responses (see especially Thompson et al. 2010).

One area where new tools may be useful is in the development of specific discourse strategies or moves for teachers as we have described them here for orchestrating scientific discourse. A number of professional development projects in mathematics have sought to help teachers develop discourse moves to help advance mathematical argumentation in classrooms (Jacobs and Ambrose 2008; Michaels et al. 2002; Mumme and Caroll 2007; Shechtman et al. 2010). One example is the Bridging Professional Development project, which taught teachers specific moves for supporting argumentation within a framework that emphasized the improvisational nature of teaching. Specific techniques from improvisational theater reinforced the idea of teaching as contingent on student response. Evidence from a small experimental pilot study indicated that relative to controls, teachers in the project supported more and longer episodes of mathematical argumentation in their classrooms.

Work that extends and translates the insights from mathematics education for science education is needed. Already, such efforts are underway and reflected in emphases within consensus volumes such as *Taking Science to School* (NRC 2007). In addition, the team that designed the curriculum unit shared our conclusion and developed additional resources illustrating ways to develop questions to support future teachers' enactment. These resources included video exemplars from the two teachers in the study who were more successful in developing student questions. For its part, the district in the study plans to share our list of discursive moves with its science instructional coaches. Their plan is to use the moves as a lens for observing and mentoring teachers to make the most of the curriculum materials.

The present study examined the initial attempts of three teachers to orchestrate discourse in the context of enacting learner-centered science instruction. It did not permit a fine-grained analysis to distinguish how successful the two teachers were who had a broader repertoire of moves for developing questions. It may be that some strategies are more effective with some students depending, for example, on their prior experience with planning investigations. Future research is needed on strategies to develop students' questioning skills, comparing the efficacy of different sequences of moves for developing questions. We envision an experimental study in which increased numbers of teachers are randomly assigned to different conditions so that causal claims can be made between instructional moves and student learning outcomes.

Given that questioning is so fundamental to science and that most students remain novices at posing and investigating their own questions, research in this area is important for science education researchers to pursue. Further, although identifying some moves may be simple and straightforward, orchestrating their use to construct coherent, effective sequences of moves takes time and is likely to develop primarily through reflective practice. Understanding teachers' development of skills in orchestration represents yet another important area for future research.

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