Eliciting and Developing Students' Ideas and Questions in a Learner-Centered Environmental Biology Unit

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Abstract: An important instructional practice for teachers in learner-centered science classrooms is to be able to work productively with students' ideas and questions. Eliciting and thoughtfully attending to students' thinking in order to help them advance in their learning is no easy matter, however. This study examined how teachers enacted instruction to elicit, connect, and build upon their elementary students' ideas and questions during an innovative twelve-week learner-centered environmental biology unit. The purpose of the study was to identify and describe successes, issues, and challenges related to incorporating students' ideas and questions into science instruction. Primary data sources included field notes taken during classroom observations and teacher interviews. We present three contrasting cases of teachers to highlight evidence that shows teachers' differing strategies for eliciting students' ideas and questions, and for developing students' ideas, questions and questioning skills. We discuss practical implications for designers of inquiry-based science curricula and professional development.

Introduction

Learning sciences research has identified as a key design principle that learning environments must be "learner-centered," that is, they must attend to and make use of what students bring to the classroom learning situation (National Research Council [NRC], 2000a). 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 & 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, Perry, & Stigler, 1989).

To support student sense-making effectively in learner-centered science environments, teachers need to shift from the typical pattern of talk in classrooms (e.g., Cazden, 1988; Mehan, 1979) to new forms of discourse that promote productive thinking and participation. In addition, teachers need to be able to make creative use of the diversity of student ideas during instruction. This entails making productive adaptations to students and their contributions as instruction unfolds. A challenge for designers is to develop flexibly adaptive curriculum materials (Schwartz, Lin, Brophy, & Bransford, 1999) that provide the structure for teachers to enact ambitious science instruction while at the same time provide support and room for teachers to make use of what students bring to the learning context. Even with such materials, teachers are likely to diverge in their approaches to and success in creating richer forms of discourse in classrooms.

In this study, we examined teachers' instructional moves to elicit and develop students' ideas and questions as they enacted a twelve-week learner-centered environmental biology unit with their fifth grade students. The unit was designed specifically to help teachers reconfigure their classrooms for science learning in ways that were more learner-centered, with a particular focus on creating opportunities for teachers to elicit and work with students' ideas and questions as a source for student-led investigations of habitats. 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.

Theoretical Framework

Formulating and refining questions that can be answered through scientific investigations is a fundamental ability required for science inquiry (NRC, 1996, 2000b, 2007). Developing scientific questions is a creative act at the heart of scientific activity (Shodell, 1995). In practice, however, student questions are rare in classrooms, compared with teacher questions (Carlsen, 1993; Dillon, 1988). Moreover, students find it challenging to take an ill-formulated question posed at the outset of an inquiry and clarify or refine it in ways that can productively guide inquiry (Krajcik, Blumenfled, Marx, & Soloway, 2000; Lehrer, Giles, & Schauble, 2002; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001). Thus, a critical challenge is to help teachers use curriculum to enable students to both to generate and develop questions that can guide inquiry.

Research on student question generation suggests that teachers' actions are critical. When teachers establish discourse patterns (e.g., brainstorming, "K-W-L" sequences) 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, Yarnall, Koch, & Roschelle, 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 & Chia, 2006; King, 1994; Reeve & Bell, 2009).

Not all student-generated questions can be investigated in classrooms and those that can be pursued 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 & Bereiter, 1992). Teachers can encourage the latter type of questions by engaging students in extended problem solving activities (Chin, Brown, & Bruce, 2002) and in student-led investigations (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005). In addition, putting students into collaborative learning situations where they must clarify questions and design investigations together can help develop students' questions (Marbach-Ad & Sokolove, 2000). Finally, teacher discourse moves such as "revoicing" that explicitly align different student contributions and ideas to content and to set up contrasts among students helps develop questions provides a motivating context for the development of questions (O'Connor & Michaels, 1993).

Curricular Context

The research described here is part of a larger design-based research project that included the creation of an elementary school science inquiry unit as a means to support science instruction that is challenge-based (Schwartz, Lin, Brophy, & Bransford, 1999), leaner-centered (NRC, 2000a), 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. Cornerstones of the unit were student-choice and student-driven inquiry related to an over-arching challenge, all couched in socially interactive group work. The newly 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). In this curriculum unit, titled *The 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 included features that are *educative* (Davis & Krajcik, 2005), meaning features meant to help teachers learn, to better support student learning. Educative features in the materials included overviews of the instructional stance, organization, and phases of the unit, flexible pacing guides that supported teacher planning, and embedded notes that signified decision points (i.e., critical junctures) during instruction where it was especially important to attend to student thinking. The lesson materials also included prompts such as idea generating (e.g., brainstorming) and questioning prompts that were meant to help teachers elicit student ideas and questions. Materials for students included an *idea journal* for developing and recording ideas and questions and for iteratively investigating key questions as they progressed 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 initially piloted the unit 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 focus of the professional development sessions included instruction on science content, descriptions of lessons and activities, modeling of lessons and activities through video clips, pacing of the unit, 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 the formal professional development sessions, the teachers were in close contact via email and in-person meetings at school sites with university researchers who were involved in the unit development. This frequent electronic and in-person communication, or "just in time" professional development provided individualized support to the teachers while they were enacting the unit in their classrooms.

Methods

The overarching research question guiding this study was, *For a curriculum unit that aims to develop students' skill in posing scientific questions, how do teachers vary in the ways they elicit, re-voice, connect, and/or build upon students' science ideas and questions?* We approached the question by focusing, as past research has, on teachers' instructional moves to elicit and help students to go further with their ideas and questions. By analyzing differences among teachers using the same curriculum materials, our comparative case approach enabled us to examine how teachers' enactments shaped their students' learning opportunities.

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 of the teachers from three different schools in the district. The three teachers, Ms. Atwell, Mr. Jimenez, and Ms. Lesh (pseudonyms), were purposefully selected as contrasting cases for the present study. Mr. Jimenez was a M.A.-level teacher in his 15th year and taught at an elementary 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 was a M.A.-level fourth-year teacher who taught at an elementary school that was predominately Caucasion (60%) and Asian American (19%), with a small percentage of students receiving free or reduced price lunch (13%). Ms. Lesh was a B.A.-level fourth-year teacher at an elementary 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.

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 and Mr. Jimenez' students scored lowest. Ms. Atwell's students scored in the middle. Preliminary analyses of observation data suggested these three teachers also differed with respect to 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 lessons 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.

In analyzing narratives, we developed and employed a coding scheme based on discourse interactions, focused particularly on patterns of teacher "uptake" (Nystrand & Gamoran, 1991) of student ideas and questions during instruction. The coding scheme was developed through an iterative process of creating codes based on hypotheses, coding evidence of elicitation and uptake, modifying and refining codes, and recoding consistent with recommendations for qualitative data analysis by 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. In instances where both coders were uncertain about a piece of evidence, a third researcher provided judgment to help clarify and reach agreement. A short statement of justification was written for each piece of evidence that linked the evidence to a code.

Interviews were conducted with each teacher at two time points: once midway through the unit and a second time 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 provided to 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 take as their aim not simply to describe the phenomena under study, but to seek out 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

In this section we highlight evidence from our analyses focused on 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. Though we identify and describe instructional moves separately, we recognize that they are oftentimes intertwined during instruction and that teachers typically enact sequences of moves to support learning.

Overall, our findings show that all three of the teachers were effective in employing instructional moves to elicit student ideas and questions. Moreover, their strategies for eliciting were similar. However, teachers differed widely in their next step instructional moves and how they worked with student ideas and questions to help students go deeper in their thinking; the teacher whose students scored the lowest on the student assessments made the fewest of these kinds of moves. To illustrate these similarities and differences, we present below summaries of teachers' moves with examples that characterize their instruction.

Strategies for Eliciting Ideas and Questions

All three teachers used the elicitation prompts in the unit materials as well as their own strategies. Among the three teachers, we identified two common strategies for elicitation – posing questions to elicit students' ideas and questions, and inviting students' ideas and questions. The teachers used these strategies to elicit both procedural and wonderment thinking. That is, teachers asked and invited procedural questions that addressed basic information about how to accomplish teacher-structured tasks as well as how to carry out student-generated ones. They also asked and invited wonderment questions that dealt with hypothesizing and predicting, explaining and clarifying, and making sense of investigative experiences and results.

Mr. Jimenez

Mr. Jimenez tended to pose questions to elicit student thinking about procedural knowledge for engaging in tasks, such as what materials to use for investigations, the steps to follow, and how to record work. During activities and investigations, Mr. Jimenez asked basic information questions to check in on students' progress (e.g., what are you doing?) and help students in carrying out their tasks (e.g., what will you do next?) When students experienced difficulties in carrying out their procedures, he tended to pose elicitation questions to help students move forward in their investigative process (e.g, how does that help answer your question?).

Mr. Jimenez also engaged in a regular elicitation pattern of inviting students to share their group work experiences and outcomes. He tended to structure these opportunities as whole-class reporting sessions in which students from different investigative groups take 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 excerpt, Mr. Jimenez invited students to report their findings as he recorded them on a smart board:

> S1: They live under rocks and in soil.
> S2: When you touch them they roll up...
> T: Okay… what was the other comment you said?
> S: They roll up.
> T: Oh, okay, they roll up.
> S3: They are in different segments.
> S4: They have eyes.
> S5: They don't have eyes!!
> T: There is some disagreement, let's write them both down for now. If you have any other ideas, please share.

Ms. Lesh
Ms. Lesh posed procedural and planning questions to her students to ensure that they clearly understood how to do tasks and to help them in the planning process of their investigations. 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 in which they were going to examine isopods' food preferences, Ms. Lesh elicited students' ideas regarding 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. One student's response to the elicitation was to select either 3 or 5 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 the problem/issue might be resolved, rather than offering an immediate solution. She 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.

After group investigations, Ms. Lesh tended to have students report out their results as well as their successes and challenges in carrying out their investigations. Of note is that Ms. Lesh elicited wonderment questions primarily when prompted to do so in the materials (e.g., prompts in the materials to generate student-driven questions about isopods).

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 from students 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 elicitation questions were typically framed as wonderment questions (e.g., what do you think?) that probed students' grasp of science ideas (e.g., what is a habitat – what are your ideas?), their ideas about what makes for a good researchable question (e.g., what does a scientific question involve?), and the kinds of questions that students were working with (e.g., what is your question?).

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 means?), build upon (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 that served to frame students' investigations and guide their inquiries. In addition, students in all three classes appeared to benefit when 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. Here we highlight the diverse ways in which teachers attended to student thinking.

Mr. Jimenez
Mr. Jimenez tended to incorporate student thinking into whole-class activities and discussions, but often did not go beyond simple acknowledgement of students' contributions. There were very few instances where he tried to really work with students on developing their ideas. When he did try to do so, it tended to be in the context of supporting students in designing investigations. In the following excerpt, Mr. Jimenez tried through his elaborations and questions to support students in thinking about controlling variables in their procedures:

> T: So, what materials do you think are necessary to do this investigation or experiment?
> S: Soil.
> T: Soil, okay (writes on "soil" on board). About how much soil do you think is necessary for this?
> S: A handful.
> T: 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?
> S2: Use cups.
> T: 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 Mr. Jimenez incorporated student thinking into whole-class activities was by having groups report out on their group activities and learning, and asking individual students to share ideas and questions. But when students shared results, posed a question, or raised an issue, he tended to simply acknowledge the contribution and would then move on to another topic. For example, when Mr. Jimenez encouraged groups to bring out their ideas, he often responded to contributions by saying "next group", "okay", and "so, now we are going to…". In this way, Mr. Jimenez structured discourse so that ideas and questions were elicited but fell short on leveraging those contributions to help deepen students' thinking.

Ms. Lesh

Ms. Lesh actively worked with students to ensure that their questions and procedures were feasible. She regularly pressed students to refine their questions, often engaging individual students in elaborating on their questions so she could then help tighten them. When pressing students to be detailed in their procedures, she explained that as scientists "you 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 tended to revoice their questions and press them to elaborate. Through her questions of their research questions, students were prompted to clarify and make their questions more feasible for classroom investigation.

During end-of-investigation discussions, Ms. Lesh connected student findings and insights to the work of other groups when the opportunity arose. For example, when a student reported observations that were similar to the work of another group, Ms. Lesh made explicit the similarities in findings. When Ms. Lesh took up students' conceptual ideas, she tended to value and validate their ideas with supportive comments like "you've got it" and "excellent" and expressing excitement through gestures such as high fives. When students were off the mark in their ideas, she tended to try and redirect student thinking through clarification questions (e.g., are you really asking about day or are you interested in light vs. dark?) and explaining her interpretation of students' ideas.

Ms. Atwell

Ms. Atwell worked continuously with students to help them learn how to ask researchable questions. In the following excerpt, she asked questions to help a student refine a question, and also used the conversation to model for the class how she was thinking when listening to what students were saying:

S: what does the climate need to be for them?
T: what do you mean by climate?
…
T: (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.
T: (to student who asked question) We have temperature questions, but it seems like you're going a little further.
S: Does the isopod's habitat need to be hot and dry or cold and moist?

Ms. Atwell held inquiry discussions and 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 the class, "does anyone want to respond?" She then allowed students to ask clarification questions regarding the initial prediction and encouraged students to provide reasons why they did or did not think the prediction would hold true. In this way, she established a discourse environment in which students saw their task as sense making and knowledge building.

Similar to Mr. Jimenez and Ms. Lesh, Ms. Atwell asked groups to report out their designs for their student-led investigations and, once investigations were conducted, encouraged groups to report their findings. Differently, however, Ms. Atwell tended to pose questions, encourage students to pose questions, and gave clear feedback when recognizing student 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:

S1 (G1): Since in the first investigation they liked the moist side…
T: Good thinking – I like how you built on knowledge you already had.
S2: I have a question, why did you decide to do it like that?
S1 (G1): We wanted to have it super light and super dark on each side.
T: So, were you thinking if you had more contrast you might get better data?
G1: Yes *(multiple students respond).*
T: Thanks team.

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 potentially help explain observed differences in student learning across classrooms. In Mr. Jimenez' class, where students scored lowest on a test of their skill in posing investigable questions, the teacher made few moves to help develop student thinking. By contrast, in the two other classrooms where students did better on the assessment, the teachers used multiple strategies for developing student 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, there was significant variation in how teachers took up the materials.

Implementation variation of this kind is hardly surprising (see, for example, Schneider, Krajcik & Blumenfeld, 2005), but the particular ways teachers varied and were similar in this study points to specific aspects of developing students' questioning skills that future curriculum materials may need to consider. 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 interesting to enact. By contrast, teachers had a harder time consistently helping students develop their ideas. Sometimes, as we report elsewhere (Phillips, Harris, Penuel, & Cheng, 2010), it was because teachers had to balance considerations of time with the need to give students multiple opportunities to develop their thinking. But in the successful teachers' classrooms, we also found evidence of classroom norms developed through sequences of moves described above. The individual moves employed were in some cases simple and straightforward, but orchestrating them in class was a skill that varied from teacher to teacher in the study. A single move can be described and pointed out easily, but learning how to orchestrate them into coherent, effective sequences of "next step" moves takes time and is likely to develop primarily through reflective practice.

One conclusion from our findings is that the IHC curriculum materials must provide greater educative support for teacher learning to develop students' questions. The team that designed the unit shared our conclusion and developed additional resources to support future teachers' enactment that illustrate ways to develop teacher questions. Some of 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 take the results of our implementation analysis and share our list of discursive moves with 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.

Future research is needed on strategies to develop students' questioning skills that compare the efficacy of different sequences of moves for developing questions. Our analysis did not permit a fine-grained analysis to distinguish how successful the two teachers who had a broader repertoire of moves for developing questions were. It may be that some strategies are more effective with some students, depending, for example, on their prior experience with planning investigations. Given that questioning is such a fundamental aspect of science and most students remain novices at posing and investigating their own questions, research in this area is an important focus for learning scientists to pursue.

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