Student and Teacher Questioning during Conversations about Science

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Abstract: This paper summarizes case studies developed by a group of collaborating educators. We investigated ways of speaking that encourage students to (a) formulate insightful questions about science topics and (b) express their own ideas during reflective discussions. The authors include elementary, high school, and college faculty. Subject-matter contexts included phases of the moon, motion, electricity, light, and waves. In developing case studies, we documented and interpreted student and teacher questions during the three ways of speaking we value most: guided discussions, student-generated inquiry discussions, and peer collaborations. Student questions occurred when we set up discourse structures that explicitly elicited student questions, engaged students in conversations about familiar contexts in which they had made many observations over a long time period, created comfortable discourse environments in which students could try to understand one another’s thinking, and established small groups where students were collaborating with one another. Typically we elicited student thinking by asking questions that develop conceptual understanding. These included questions to help students clarify their meanings, explore various points of view in a neutral and respectful manner, and monitor the discussion and their own thinking. We also elicited student thinking by practicing quietness through long wait times, attentive silence, and reticence. © 2001 John Wiley & Sons, Inc. J Res Sci Teach 38: 159–190, 2001

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Introduction

This paper reports upon common themes in case studies of questioning developed by a group of collaborating educators. Participants in this project included teachers and their students at elementary school, high school, and university levels. We have been investigating ways of speaking that encourage students to (a) formulate insightful questions about science topics and (b) express their own ideas during reflective discussions. Although our instructional approaches differ in many ways, we share a commitment to fostering active student thinking through educational practices that often are described as “constructivist” (Fensham, Gunstone, & White, 1994).

Our work contributes to the growing literature on the nature of dialogue during science instruction (Abell, Anderson, & Chezem, 2000; Carlsen, 1991; Collins & Stevens, 1982; Driver, Newton, & Osborne, 2000; Gallas, 1995; Hogan, 1999; Kelly & Crawford, 1997; Lemke, 1990). Teacher questions are a frequent component of science talk. Of particular interest are questions that elicit what students believe and why (Arons, 1983; Driver, 1983; Roth, 1996; van Zee & Minstrell, 1997a,b). Student questions rarely occur in classroom settings (Dillon, 1988). Their number and thoughtfulness may increase, however, when teachers increase “wait time” before calling on students (Rowe, 1986; Tobin, 1987) or when teachers make statements rather than asking questions (Dillon, 1985).

The value of student questioning has been emphasized in the National Science Education Standards, which states that “inquiry into authentic questions generated from student experiences is the central strategy for teaching science” (National Research Council, 1996, p. 31). We interpret this to mean that students should be involved in formulating questions to explore. In addition, students’ questions can be valuable during discussions. They indicate that students are actively engaged in making sense of what they are learning and may articulate issues that need to be addressed. During such discussions, students may generate questions that form the basis for the next steps in instruction.

In our case studies, we have presented specific examples of student and teacher questions during conversations about science, provided details about the instructional contexts in which these questions occurred, and interpreted these dialogues. Our intent has been to provide analyses that can be useful both to teachers interested in shifting toward more reflective practices and to researchers interested in the nature of productive questioning in classroom settings. We believe that these case studies illustrate practices advocated in reform documents such as Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) and the National Science Education Standards (National Research Council, 1996). We have used the case studies as contexts for discussing such practices with prospective teachers (van Zee, 1998).

Although our teaching environments differ in many respects, we share the belief that students learn by engaging in spirited discussions about topics that interest them. We agree with Tharp and Gallimore (1988) that such conversations may have common properties whether they occur among children in elementary school or adults in graduate seminars. In this paper, we examine common themes across our individual case studies in order to identify ways of speaking that seem to foster student questioning and thinking about science topics in diverse circumstances.

Typically university researchers have conducted studies of questioning in the classrooms of anonymous teachers. The co-authors of this paper, however, include teachers who have collaborated with one another and with a university researcher in investigating questioning in the context of their own teaching practices. Thus, these case studies also contribute to the emerging
literature by teachers as researchers in their own classrooms (Cochran-Smith & Lytle, 1993; Gallas, 1995; Hubbard & Power, 1999).

Research Issues

Ways of speaking during science instruction include lectures, recitations, guided discussions, student-generated inquiry discussions, and small group interactions. We developed a framework to represent attributes of these discourse practices as indicated in Table 1.

During a lecture, the teacher transmits knowledge to students by telling them information. Such knowledge typically consists of facts to memorize and procedures to practice. One issue is the effect of speed of transmission on student acquisition of information (Dhindsa & Anderson, 1992). During a lecture, the teacher is responsible for expounding clearly; the students for listening carefully and remembering accurately. On-going assessment includes noticing whether students are attending. Tests typically consist of many short-answer and multiple-choice questions; successful performance requires recalling information and executing problem-solving procedures covered in the text and lecture. During a lecture, the teacher may ask and answer rhetorical questions. Student questions are rare and may be limited to the end of class. Some teachers may close a lecture by inviting students to write questions and then open the next lecture by addressing the issues raised (Gastel, 1991, p. 28).

During a recitation, the teacher asks questions to check on student knowledge (Initiation), listens to students’ answers (Response), and assesses the correctness of these responses (Evaluation). Sometimes called an IRE (Mehan, 1979), this three-turn structure seems to be ubiquitous, appearing as early as preschool (Kleifgen, 1990) and in a wide variety of subject matter contexts (Dillon, 1988). Lemke (1990) named this triadic dialogue and found it to be the predominant structure of discourse in high school science classrooms. As with lectures, the knowledge taught typically consists of facts and procedures. During recitations, the teacher is responsible for judging the students’ answers; students for producing answers that agree with the teacher’s expectations. On-going assessment includes monitoring the accuracy of responses during the recitation. As with lectures, tests typically consist of many short-answer and multiple-choice questions; successful performance requires recalling information and executing problem-solving procedures covered in the text and rehearsed during the recitation. During recitations, teachers primarily ask “test” questions to which the answers are already known. Student questions are rare (Dillon, 1988). When student questions occur, the teacher may interpret them as a challenge to authority and choose not to interrupt the agenda to consider them (Baird & Northfield, 1992).

During a guided discussion, a teacher constructs knowledge with the students by making comments and asking questions to develop their understanding of a topic. Such knowledge involves more than memorizing facts and executing procedures; the students are expected to refine what they already know in order to comprehend complex topics. During guided discussions, the teacher is responsible for eliciting and facilitating the students’ thinking; students for expressing their own ideas, especially when these disagree with the teacher’s expectations. On-going assessment involves monitoring evidence of changes in individual students’ understanding as well as in the evolving consensus of the group. Tests typically consist of a few integrative questions that involve substantial writing; successful performance may require perceiving connections among disparate entities and applying understandings in new situations. During guided discussions, teachers primarily ask conceptual questions to elicit student thinking. They usually welcome student questions and may adjust the agenda in order to consider some of these at length (Baird & Northfield, 1992; Roth, 1996; van Zee & Minstrell, 1992).
<table>
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1997a,b). Settlage (1995) provided an excellent example of a guided discussion in which a teacher explored her students’ ideas about light. The teacher’s contributions were primarily elicitations, such as “Do you think so? Tell me why.”

During a student-generated inquiry discussion, students construct knowledge with one another by asking questions and explaining their understandings. Such knowledge involves more than memorizing facts, executing procedures, or comprehending complex topics; the students often formulate key issues for consideration. The teacher is responsible for facilitating the students’ creative work; the students for inventing and designing ways of thinking. On-going assessment includes monitoring what the students are saying for aspects that may be productive in moving the inquiry forward, even if these differ from scientifically accepted views. Because student-generated inquiry discussions often evolve from guided discussions, the students’ learning typically is evaluated formally in the same way, through writing responses to integrative questions. During student-generated inquiry discussions, teacher questions are rare but student questions occur frequently and spontaneously. The students may erupt into a “cacophony” (Gallas, 1995, p. 37) in which they vociferously share their thinking. Gallas perceived these to be moments during which students made great progress in developing their understanding. Examples of student-generated inquiry discussions include intense interactions during which sixth graders “invented graphing” as they designed ways to represent motion (diSessa, Hammer, Sherin, & Kolpakowski, 1991) and high school physics students discussing a dropped ball on a moving ship (Hammer, 1995).

Small group interactions with the teacher present are similar to guided discussions. During small group interactions without the teacher present, students construct knowledge by asking one another questions, explaining their understandings, and doing tasks that provide a context for their asking and explaining. In addition to subject-matter knowledge, students are expected to be learning ways to engage in independent yet collaborative thinking. The teacher is responsible for monitoring students’ progress from afar; the students for inventing and designing their own ways of thinking and doing. On-going assessment includes monitoring whether the students are trying to make sense together of whatever they are doing and thinking. Small group work often provides the basis for guided discussions and student-generated inquiry discussions. Formal evaluation similarly may involve writing substantive responses to integrative questions. During small group collaborations, the teacher is not present and asks no questions. Student questions occur frequently and spontaneously as students work together. Roth and Bowen (1993, 1995), for example, examined ways in which questions emerged from student interactions with one another and with the settings for their inquiries about ecozones near their school. Hogan, Nastasi, & Pressley (2000) documented the pivotal role of queries in prompting students to think deeply during small group collaborations without the teacher present.

We have developed case studies of questioning within the three ways of speaking that we primarily use during science instruction: guided discussions; student-generated inquiry discussions; and small group interactions. Our intent has been to contribute to knowledge about student and teacher questioning by assembling explicit examples and interpreting these from the perspective of the teachers who were engaging their students in the conversations.

In this paper, we examine aspects of student and teacher questioning that occurred across our case studies. Specific research questions included the following:

- What factors fostered student questioning during the dialogues documented and analyzed in these case studies?
- How did teacher questioning elicit student thinking during these dialogues?
Method

We consider this research to be in the tradition of ethnography of communication (Hymes, 1972; Philipsen, 1982, 1992). We have analyzed ways of speaking in classroom cultures in which students develop understandings by talking together about science topics. The case studies express interpretations from the perspectives of the teachers in whose classrooms the dialogues occurred.

Settings

During the period of this project, Iwasyk and Kurose were teaching in urban elementary schools with racially, linguistically, and social-economically diverse students. Wild and Simpson were teaching in suburban schools with primarily white middle class students, Wild in a parochial elementary school and Simpson in a public high school. van Zee was teaching science education courses with primarily white middle class students, in two public research universities.

All of us engaged our students in watching the moon and talking about what they had seen over many months. Other subject matter contexts depended upon the curriculum in use in each classroom. Other topics included light and shadows (Iwasyk), arithmetic (Iwasyk), electricity (Wild), force and motion (Simpson), and waves (Simpson).

Participants

Participants included two primary teachers (Iwasyk and Kurose), an upper elementary teacher (Wild), a high school physics teacher (Simpson), a university researcher who is the principal investigator for the project (van Zee), and our students. All of the participating teachers and the university researcher are females from middle class backgrounds; four of us are white (Iwasyk, Simpson, van Zee, and Wild) and one Asian American (Kurose). The teachers and university researcher initially met while participating in physics programs designed to prepare teachers to teach science by inquiry (McDermott, 1990, 1995). We share a commitment to engaging our students in talking together about what they think as they explore physical phenomena.

Data Sources

Data sources included audio- and video-tapes of instruction; tapes of subsequent research conversations, collaborative meetings, and student interviews; written reflective commentaries by the participants; and copies of student written work.

Development of the Case Studies

The term “case study” is used in many ways for many purposes (Merseth, 1991; Wolcott, 1992; Yin, 1984). Shulman (1991), for example, engaged teachers in writing cases based on their own experiences that could then be used to ground discussion of complex issues in professional development settings. Such cases typically end with a presentation of a dilemma and invite consideration of ways to respond. Colburn & Tillotson (1998), for example, presented such a case for use in a science teaching methods course.

We have chosen to focus upon positives by identifying dialogues that we perceive to be productive and interpreting the questioning that occurred within these. Our purpose has been to provide explicit examples of discussions that might help teachers interested in shifting toward
more interactive practices. Analysis involved (a) identifying instances of active student thinking in which students expressed their own ideas in comments and questions and (b) examining what these ideas were and how they were elicited by the teachers, by other students, or by the speaker themselves in the process of speaking aloud.

The process by which we developed the case studies evolved during the project. Initially the university researcher (van Zee) identified learning events of interest while videotaping in a participating teacher’s classroom, interviewed the teacher during free moments that same day, transcribed relevant portions of the tape, wrote interpretations, and checked these as soon as possible with the teacher. Typically she went through several cycles of checking interpretations, reinterpretng, and revising. When possible, she invited participating teachers to accompany her to professional meetings to report upon the work as co-authors (van Zee & Iwasyk, 1994; van Zee, Kurose, & Schnabel, 1993; van Zee, Wild, & Flanagan, 1993).

The early part of the project served as fortuitous research apprenticeships for the teachers, who then chose to undertake such research themselves when it was no longer feasible for van Zee to videotape in their classrooms. Later in the project, the teachers collected their own data, selected learning events of interest, transcribed, interpreted, wrote papers reporting their findings, and presented their work at professional meetings as first authors or sole authors (Iwasyk, 1997; Iwasyk & van Zee, 1995; Kurose, 1997; Simpson, 1997; Simpson, Minstrell, & van Zee, 1995; Wild, 1995, 1997). Although now working at a distant institution during the academic year, van Zee was able to meet with the teachers individually during the summer at their homes for a series of extended conversations about their work. We also met several times as a group during the school year in one of the teacher’s classrooms when van Zee was visiting the area.

Development of Analysis across Case Studies

The analysis that follows is drawn from the papers cited above and our on-going studies. As we shared our work with one another, we noticed common insights and experiences emerging in the individual case studies. We summarize these here as a set of assertions (Gallagher & Tobin, 1991) about student and teacher questioning. van Zee initially formulated these assertions on the basis of the case studies and a series of conversations with members of the group. The current set of assertions emerged from a reiterative process of refinement through additional individual and group conversations and feedback from anonymous reviewers and the editors. Few of these assertions are surprising. However, they constitute an emerging framework for student and teacher questioning that characterizes our experiences as individuals in very different circumstances who share a commitment to fostering student thinking and learning. Development of the analysis has enabled us to articulate explicitly cultural practices that underlie the ways of speaking we established in our classrooms. Most of the examples involve guided discussions because these primarily characterize our classrooms. Also, included are some examples of student-generated inquiry discussions and peer collaborations.

Common Aspects of Questioning across the Case Studies

We discuss below assertions about student and teacher questioning during conversations about science. The use of [brackets] indicates changes in the text such as substitution of a symbol for a student’s name. [S5], for example, refers to the fifth student to speak during the discussion being reported. T: refers to the teacher. Some teachers used capital letters to represent a student’s name, such as C. Portions of the excerpts are underlined; these illustrate the assertions being made. Three dots (…) indicate omitted utterances.
Student Questioning

We have formulated the following assertions to describe common aspects of student questioning across these case studies:

**Assertion 1:** Student questions occurred when we set up discourse structures that explicitly elicited these.

An obvious way to foster student questions is to elicit such questions explicitly during guided discussions. A common structure used in elementary schools is the KWHL chart in which the teacher asks students what they already *Know* about a topic, what they *Wonder* about a topic, *How* they could find out, and eventually what they have *Learned*. Another structure is brainstorming about a topic. A third structure involves calling for student questions as a way to close a discussion. These are discussed below.

**Constructing a KWHL Chart.** Iwasyk and her primary students often constructed a KWHL chart as a way of beginning study of a topic. After the children returned from winter vacation, for example, Iwasyk re-introduced their moon studies with a guided discussion as follows:

T: Remember when we talked about worm bins and we talked about what we already know about worm bins and then we talked about what we want to know, what we want to learn? We’re going to do the same thing now about the moon. What are some of the things we know about the moon, things we already know?

First the students listed various shapes they had seen and then one of the students launched a discussion about why the shape changes, stating that “I know *why it changes shape*. It’s behind the clouds.” This is a common explanation, even among adults, and likely reflects the everyday experience of sometimes seeing moving clouds cover the moon. Another student offered an explanation likely derived from conversations with his scientist parent:

S1: Well, *why the moon changes shape* is not because it’s behind the clouds. It’s because the sun moves around the moon and when the sun’s shining on one side of the moon, it makes the moon look bright. If it’s shining on the other side, you can’t see it at all.

Another student contributed some thoughts likely based on personal experience:

S10: The clouds aren’t in outer space. They’re part of the environment cuz airplanes go over the clouds.

In discussing what they already knew, these students were comfortable stating what they thought and why they thought that. They had learned to consider what was being said and to offer opinions and insights based on their perspectives and experiences.

After another student contributed information about seeing the moon sometimes in the morning, Iwasyk asked explicitly for questions, “Anything else that we know? Is there anything that you would like to find out about the moon?” Many students posed questions that appeared to have cultural origins such as cartoons or myths. One student asked, for example, “*Does the moon talk?*” Another asked, “*I would like to know about if there’s such a thing as a man on the moon*?” Iwasyk nurtured the children’s interest in cultural as well as physical phenomena by reading stories about the moon from other cultures such as North American Indian myths about a
rabbit on the moon. Through such experiences, the students learned not only about the moon but also about different cultures’ interpretations of a common phenomenon.

One of the students articulated an issue that appeared to be connected to an earlier discussion:

S9: If someone was really going to walk on the moon, I wouldn’t think the moon was flat because if somebody was going to walk around the moon to the bottom of the moon, 
they might fall off or they might not fall off.

T: Like how people used to believe using Christopher Columbus’ idea about the earth, you mean? Oh, that’s an interesting thought.

While reflecting on this student’s contribution, Iwasyk noted that he may have been making a connection to a conversation several months earlier about the belief that the earth was flat and that Columbus might sail off the edge. She commented that she wants her students to learn to make such connections although she likely did not pursue this further in this case because it was almost time for recess.

Brainstorming. Kurose also explicitly elicited student questions during guided discussions. Occasionally she gathered her first-grade students in a circle and brainstormed together to generate questions about a topic they had been studying. She welcomed call outs of questions without recording these in order to encourage spontaneity. Her students asked the following questions during a videotaped brainstorming session about the moon, for example, after they had been watching it for many months:

How do we get the phases of the moon?
Why does the moon look like it is following you?
Why does the moon have a face?
How come the moon shines white? Why not red? or orange? or yellow? or blue?
Why are there craters on the moon?
Do the moon and the earth ever bump into each other?
This morning I saw a very thin moon, a very thin crescent moon. What kind of crescent moon was that?
How did the moon get up in the sky?
Can we go to the moon now? I want to take a field trip to the moon.

After eliciting such questions orally, Kurose asked her students to write their questions so that they could remember them, share them, compare them, and perhaps try to find out some answers. She believed that the number and quality of her students’ written questions reflected both their extensive experiences in watching the moon and the generative effect of the brainstorming session. The question “How come the moon shines white? why not red?” for example, likely derived from watching both the moon and the sun. “Why is there a moon?” was one of the questions generated during the brainstorming session. In addition to learning how to formulate questions, these first grade students were building a base upon which they could draw in considering different kinds of questions and ways of answering. They also were learning how to write what they were thinking, to translate ideas generated during an oral activity into the written word.

Closing a Discussion with Student Questions. van Zee sometimes closed guided discussions by asking students to list the questions they had at that point. For example, one of
the prospective teachers in van Zee’s course on methods of teaching science in elementary school (van Zee, 1998) listed questions on chart paper as classmates offered their ponderings. The chart of questions lengthened during subsequent discussions and eventually each small group formulated a question to guide their coming observations. Some of the prospective teachers’ questions were:

- Does the moon rotate around the earth or does the earth rotate around the moon?
- Why and when are the sun and moon out together at the same time?
- How does the moon’s position change in relation to the sun?
- What determines the direction of the lit portion?
- What causes the moon to appear as different shapes?
- Why is the moon sometimes not visible for several days?

The small groups explored some of these questions during their second month of moon watching. One of the prospective teachers wrote the following in reflecting upon how this assignment had fostered science learning:

> The moon paper helped to foster science learning because we were able to come up with our own questions... This allowed us to have ownership of the project. Also, this helped us be interested in the project. Through our observations we were able to come up with our own conclusions about the different patterns of the moon.

For most of these prospective teachers, this assignment appeared to be the first time that they had been asked to formulate a question and to design ways to go about answering it. van Zee perceived many of them to be somewhat puzzled and initially anxious about this assignment. Formulating their own questions, however, seemed to motivate them to keep watching the moon. These prospective teachers were learning both science content—about the moon, and science pedagogy—about teaching and learning through inquiry.

**Assertion 2: Student questions occurred when we engaged students in conversations about familiar contexts in which they had made many observations over a long time period**

We found that students asked questions grounded in their observations, particularly in the context of the moon studies after they had been watching for a long time. In each of these classrooms, from kindergarten to the university, most of the students began with little formal knowledge about the phases of the moon and informal knowledge that was limited in application. For example, “To see the moon, I should look in the evening” is appropriate for some of the phases but not for all. Sometimes when the moon was visible during class time, we took our students outside to view the moon and to draw what they were seeing. During discussions of the moon, the students asked many questions, some of which were unexpectedly sophisticated in perceiving the next step in thinking or raising philosophical issues.

*Perceiving the Next Step.* Kurose documented the emergence of a first-grade student’s question that was highly abstract and perceptive. This question emerged spontaneously during a guided discussion of moon observations one of the students had made while visiting Australia. These first-grade students had some understanding of where Australia was with respect to their own location in Seattle because they gathered daily on a floor area that had been covered with a durable world map. They could choose to sit on the continent of Australia, or on their home on one edge of the continent of North America, or on the ocean in between, or on anywhere of interest anywhere in the world. Many of the children in the class came from other countries and they frequently identified these countries on the world map on the floor or on a world globe that
was stationed conveniently near their gathering spot. With the globe, they could see the line called the equator and the three-dimensional relationships of countries above and below this line. The student had continued her moon observations while she was visiting in Australia and when she returned to Kurose’s class, she and her classmates compared their moon calendars. They found that their moon drawings looked different: The children in Seattle had recorded crescent moons getting bigger on the right (i.e., crescents that looked like increasingly fatter backwards Cs). The child visiting Australia had recorded crescent moons getting bigger on the left (i.e., crescents that looked like increasing fatter forward Cs). Kurose guided the discussion by asking for an explanation for the difference in observations, by reviewing on a globe the relative locations of Seattle and Australia above and below the equator, and by explicitly articulating the issue of whether people who live in the northern and southern hemispheres see something different when they look at the sky. One of the students acted out the difference by bending himself upside down and looking at the crescent moon drawn on the board through his legs. This prompted a discussion of how the waxing crescent moon would look in a nearby country, Canada, and other places. The ensuing discussion led to a spontaneous student question that was completely unexpected.

S4: My Dad’s been to Brazil.
T: How do you think you would see the moon?
   Remember where the equator is. Make a hypothesis
S4: The way [S1] saw it in Australia . . .
T: The way [S1] saw it in Australia . . .
   So it depends upon where you are on earth.
S5: How does it look if you’re on the equator?
T: Yes. How would it be?
S5: It might look like in between
   T: So would it be like this? (draws a crescent moon curving upward like a smile) or like
   this? (draws a crescent moon curving downward like a frown).
S5: No
   T: Let’s think about it.
S5: The one above it might see it kind of, like up, and the one below might see it like [S1]
   did.
T: Let’s find out, okay? I really don’t know how it would look like at the equator. I never
   thought about it . . . that’s something you might research.

In reflecting upon this conversation, Kurose wrote:

This entire process of observing the moon becomes part of their daily experience and becomes cooperative in nature, as they are able to share what they have learned and observed with their families, as well as with other students . . . The children’s exposure to and experiences in our daily moon gazings over a several months’ period nurture their abstract thinking and questioning skills. In one conversation about observations, a child casually inquired, “How does the moon look if you’re on the equator?” This question was neither prompted nor expected . . . Because of the manner in which we study the phenomena of the moon, children’s questions are real; and because their curiosity is piqued, the answers to the questions are crucial; as they genuinely want to know.

The first-grade student’s question about how a crescent moon looks on the equator was spontaneous. Its’ emergence, however, depended upon many factors. This student had enough knowledge about crescent moons and about locations on earth to be curious about one topic in the context of the other. Also important was the extended conversation within which the student
asked this question. The children had compared observations made by themselves and by a
classmate from two locations; they had connected differences in these observations to differ-
ences in the location of the observers with respect to the equator; they had considered “What
does the moon look like from X?” for a variety of locations; and they had begun to connect their
responses to whether X was above or below the equator on the globe.

S2 was able to perceive and articulate the next step, to wonder what the moon would look
like on the line that was being used as the criterion for deciding which way the crescent would
appear. He was learning to listen to what was being said, to make sense of it, and to generate a
question to articulate a missing piece. That his teacher had never thought about this question
herself was potentially threatening, he was asking something to which she did not know the
answer. She was familiar, however, with the experience of being asked penetrating questions by
her students. Kurose responded to this unexpected question by eliciting the student’s ideas,
acknowledging that she had never thought about this before, and articulating the need to
investigate further. She then deepened the students’ global understandings by closing the
conversation with a story about the moon from Africa (Bess, 1983), which she invited her
students to read critically on the basis of their detailed knowledge about the moon.

Pondering the Nature of Change. A fifth-grade student raised a question with deep
philosophical roots—are the changing phases of the moon discrete or continuous? This was a
spontaneous question that emerged while Wild was guiding a discussion about when various
phases of the moon might be visible.

T: ...now we know we can go out at 9 o’clock and midnight [to see a full moon] And
any other times? [S3]?
S3: Does the moon change... going from 3 o’clock to midnight, does it change?

Wild reflected the question back to the student to make sure she had understood it. Then she
explicitly asked for the student’s opinion, based upon what the student knew:

T: If it’s a full moon, does it change?
S3: Yeah. No, if it’s a crescent.
T: If it’s a crescent, does it change?
What do you think? from what you know about the moon?
S3: I don’t think it does.

Wild followed up on this response with a question that explored the situation further. This
prompted the student to formulate his question more precisely:

T: Does it make sense, that it’s a crescent for a whole day and then it changes <yeah> to
a different crescent for a whole day and then changes to another?
S3: Yeah, I mean but it doesn’t change in like an hour, does it?
T: How often, that’s a good question, how often does it change?
Does it just all of a sudden by the day change? or by the hour? or by the minute?

Wild had been asking a series of questions to check student knowledge about rising and setting
times for a full moon but she shifted here to questions that helped this student articulate his own
query more clearly. She was not expecting this question and did not initially understand it but
followed the student’s lead in contemplating an interesting issue. Wild’s “What do you think?
from what you know about the moon?” is similar to Kurose’s “Yes, how would it be?” in that
both teachers made moves to elicit the students’ views rather than answering their questions. Several students responded to this student’s response and with the class ending, Wild suggested that a small group work on the issue to demonstrate it at a later date. Like Kurose, Wild left an unexpected student question open for further investigation and discussion. Like Kurose, she also brought the students back to her own agenda for what to do next, in this case closing the class with a homework assignment to figure out rising and setting times for the remaining phases of the moon. In both classrooms, the students who asked questions, and their classmates, were learning that students can generate issues that teachers find interesting and that need further exploration.

Assertion 3: Student questions occurred when we created comfortable discourse environments in which students could try to understand one another’s thinking.

Sometimes students shared their thinking with one another in what we came to call a student-generated inquiry discussion. A student would ask a question and other students would offer comments or pose related questions. A teacher could set up this structure explicitly or let it emerge by staying quiet when student/student/student exchanges spontaneously occurred during guided discussions.

Structuring a Student-Generated Inquiry Discussion. Iwasyk videotaped the conversation reported below while she and her students were working on a KWHL chart about shadows. Rather than simply listing students’ individual contributions on the chart, she used the process of constructing the chart as a context for engaging students in talking thoughtfully with one another. The students were sitting in a half circle on the floor near the chart papers hanging on a wall. Iwasyk already had invited a student who had a lot to say, C, to be one of the day’s scientists. Then she invited another student, L, to join C in this role:

L: I think I know how they are made.
T: The shadows?
L: uh huh
T: Would you like to come on up here and be our second “scientist” then?
(L positions himself within the circle.)
L: If there was a bright, bright light up here, and it does go like you were talking about (responding to the information C had shared), and then you could be right here and you’re covering part of the ground and you could be however you want.
C: I know. That’s what I said.
L: Like if we were outside you can almost always see it on grass.

Iwasyk encouraged the students to continue thinking about the issues by explicitly stating the kind of conversation she wanted the students to have, one in which the students were in charge of both asking and answering questions:

T: O.K. Have a seat there and you can answer any questions these people have. (C calls on R).
R: How, I mean, like . . .
   Why does(n’t) it have the color that you have on?
C: It doesn’t.
R: But why doesn’t it?
Iwasyk supported Rs contribution by re-stating his full question:

T: Oh, so, why doesn’t it have the color that you have on?
C: It’s not really you, it’s just
R: a part of you
C: Yeah, it’s just a reflection of you,
R: Oh, O.K.
C: black on the ground.
L: Like the sun, like you’re, you’re, like you’re a dark black cloud.

Iwasyk responded to this conversation among R, C, and L with an affirmation by making a connection to language arts:

T: Ooo, we’ll have to write a poem about that!
Meanwhile M had noticed something she wanted to share:
M: I see a shadow in the room.
Iwasyk welcomed this comment by re-articulating it:
T: Oh? You’re looking at your shadows in the room (Everyone sees shadows with sun shining through the windows—great excitement!!! Everyone talking at once.)

Through such conversations, these primary students learned how to develop a shared understanding of what they knew and wondered about a topic. In reflecting about this conversation, Iwasyk wrote:

Questioning techniques can be used by students to learn how to ask questions of themselves and of others to investigate or explore a topic of interest. Questions allow a child to become the “leader” or “teacher” as he or she enlarges or guides the discussion in a specific area, whether they are the ones asking or being asked. I firmly believe that as one teaches, one also learns; thus, children grow in their own skills as they teach others.

Iwasyk created a comfortable discourse environment by appointing students to facilitator roles, explicitly describing how she expected the students to converse, listening closely to what they said, helping clarify some contributions, and making suggestions for additional activities.

*Listening Appreciatively to a Spontaneous Student-Generated Inquiry Discussion.* van Zee documented an example of a spontaneous student-generated inquiry discussion about the changing phases of the moon in her science education seminar for undergraduates interested in teaching. The students were discussing an observation that the waxing crescent moon appeared to be higher and to the left of Venus in the western sky just after sunset on consecutive evenings. One of the students, a comparative literature major (CL), initially had mentioned this observation while she was confirming statements made by an astronomy major (AS). CL had interpreted her observation as the moon “falling behind” the sun and therefore as the moon moving “more slowly.” One of the math majors (MA1) then incorporated CLs thinking into his explanation for his prediction that the moon would be rising later and later that week by saying “so if what [CL] described as its turning slower, then it would sort of be a little bit back…” This prompted CL to question her own thinking, which initiated a discussion that extended for about 5 min without intervention from the instructor:
CL: I mean, I wouldn’t, I don’t know if, I guess I used the word “slower” but can that really be true? because
AS: That’s what I was wondering.
CL: Because it’s not really moving slower or more slowly
MA1: Doesn’t quite make it back in one day.
CL: Because it must go the same amount.

After CL reviewed her observations, MA1 and AS checked their understanding of what she had seen and when she had seen this:

MA1: Higher from the western horizon, right? <yeah> Right, west.
AS: You made an observation at the same time?
CL: Right . . . I went out at 8:05 three nights in a row.

CL then summarized her confusion and MA2 and AS asked questions to clarify their understanding of CL's interpretation. They phrased their questions in terms of the change in the angle formed by pointing one arm at the setting sun on the horizon and the other arm at the moon, a change which the students had observed as being 12 to 13 degrees each day:

MA2: . . . Well yeah, but you’re saying it might change by a different distance depending (unintelligible). It wouldn’t be 12 degrees every day.
CL: So it might be 20 degrees one day.
MA2: That’s what I thought you were saying. Is that what you were saying?

AS and CL started to speak at the same moment, and CL asked AS to go ahead:

AS: cause when I was going to ask you what you meant by “more slowly”.
I thought too that you were meaning that the speed was changing.
Sometimes it went one speed and another time it went other speeds,
But I think that you were just saying that’s not what you meant.
CL: No, I don’t think that it’s really going more slowly.
That doesn’t make sense to me.
AS: That it’s not changing speed.

After CL responded by explaining her current interpretation, AS asked permission to try to clarify further CL's thinking:

AS: Can I draw a picture of what you said?
CL: Yeah!
AS: I might, I might be wrong but if you think this is right,
Cause if this is the earth and here’s the orbit of the moon (draws on board) . . .

Although van Zee did not utter the equivalent of Iwasyk’s “Have a seat there and you can answer any questions these people have,” she listened intently and appreciatively while the students assumed responsibility for managing this conversation. These undergraduates had been watching the moon for many weeks and frequently built upon one another’s comments and questions in discussing what they were seeing. Their questions included voicing uncertainty about the veracity of one’s own interpretation, checking on the specifics of the observations being interpreted, explicitly verifying one’s understanding of the meaning of another’s statements, and asking permission to explain a colleague’s thinking. Although the astronomy major
likely already knew a lot about the moon, she never before had actually watched its changing phases on a consistent basis. Along with her classmates, she was learning both the daily details of the moon’s relation to the sun and skills for pondering the intricacies of these observations.

Assertion 4: Student questions occurred when we established small groups where students were collaborating with one another.

We are interested not only in having our students generate insightful questions about science topics but also in having them learn how to assist one another, and even themselves, in coming to understand something through appropriate questioning. Because we do a lot of small group work in our classes, we particularly want our students to be able to make progress by asking one another useful questions. The examples below are in two contexts: one student mentoring another and two groups of students collaborating by comparing their findings.

Mentoring. Iwaysk often paired her primary students to work together. She wanted the more skilful partner to mentor the less skilful partner with ways of speaking that she modeled during whole group discussions. In reflecting upon her emphasis on communication in her classroom, Iwasyk wrote:

From the first day of school, I model questioning and communication skills that I hope the children will emulate as the year progresses. Groups and pairs of children are allowed to converse a great deal during the day and so are comfortable speaking with one another.

Iwasyk wanted her students to be able to help one another in small groups by asking questions rather than telling answers. In order to monitor changes in the children’s questioning skills, she placed a microphone near a computer station and audio-taped pairs of students talking together as they worked on arithmetic problems shown on the screen. She compared student conversations recorded at the computer in October and February and reflected upon her findings as follows:

I have a few extremely capable math students in my K-1 class who had great difficulty restraining themselves during a math activity at the beginning of the year. If they discovered a pattern or an answer to a question, they just had to say it out loud. It was very important to them to get the answer first and make sure the rest of the class knew they had. While listening to the tapes, I was very gratified to hear several conversations they had with others who were doing problems on the computer. They were making a great effort not to tell the answer, but instead were asking questions to help the other child figure out the problem. One child in particular did an excellent job at this, and as he had been the worst “offender” at the beginning of the year, I felt he had made wonderful progress. In the following excerpts, he is S2:

October:

S1: [S2], I need help
S2: ... 2 + 1. What do you think that is? I’ll tell you a number. It looks like an “S” (meaning a 3).

February:

S1: 6 - 1 is
S2: ... Let’s pretend that you had 6 turtles and then 1 got taken away. How many would you have then?
S1: (Types 5 for answer)
S2: Five. Yup!
As the students have grown in their ability to ask good questions during computer math, I have noticed they have less desire to always “tell the answer” during group and individual activity times. I see more good teaching going on throughout the day in all areas, even spelling, as I hear little voices saying, “Don’t tell the answer. S/he won’t learn how to think.”

The questioning techniques can be used by students to help them learn how to ask questions of themselves if they are stuck on something. If they know how to talk it through, they can discover the answer for themselves, they help themselves figure out how to figure it out. As children become more competent in their questioning skills, they become teachers, too, and then there are a lot of teachers in the room, not just me.

Iwasyk not only asked questions to help students think through a problem, but she also explicitly talked about what she was doing. She both modeled questioning strategies and discussed these with the intent of coaching her students to become good questioners themselves. The purpose of such student questions was to help someone else, or sometimes even themselves, come to understand something better.

**Collaborating with Another Group.** Another kind of student questioning occurred when members of small groups tried to make sense of their observations. The following dialogue is an example of collaborative exchanges among members of two small groups who compared findings in an investigation they were conducting. This conversation occurred in one of Simpson’s second year physics classes during the first week of school. These students were beginning the study of waves. On the first day, they had generated questions about waves in general. They also had posed questions that they might be able to answer in the next few days by investigating how waves moved along very long springs they could stretch across the floor. Their questions included: Does the shape stay the same? How does the original size of the wave affect its speed? When waves collide, do they bounce back?

Two groups had been exploring the issue of what happens to the speed, amplitude, and length of a pulse as it moves along the spring. When one group member asked “What did you get?”, the two groups found that their findings disagreed. Although both had observed that the amplitude decreases, Group 1 reported that the pulse slowed down and got longer whereas Group 2 reported that the pulse maintained the same speed and length. Instead of appealing to the textbook or the teacher, a member of Group 2 concluded:

S21: We’ve got some more experimentation to do then.

Then he solicited information about the other group’s methods:

S21: How did you determine that it gets longer?

Members of Group 1 responded by beginning to reflect upon these two interpretations of the situation. S13 articulated the alternative that Group 2 seemed to be claiming and S11 responded with an analogy that may have governed what members of Group 1 had seen when they were doing their experiments:

S13: Well, does its amplitude just get smaller and its length stay the same?
S11: I think it gets a little longer.
   because it’s like the wave gets smaller, you know?
   It’s like the wave gets more spread out along the spring.
S21 acknowledged this perspective.

S21: Yeah, it makes sense.

Then he presented a counterargument:

S21: But it's not, it's not like a, one body that's getting spread out.
So it's not like it's the thing is the same length
and then to go down, it automatically has to get longer.

Here S11 expressed an idea that seemed to be shaped by everyday experiences. Lowering the height of a mound of leaves, for example, spreads it out. S21, however, suggested that a wave is different, that the length of the wave would not necessarily get longer if its height decreased. Groups 1 and 2 were unable to resolve their differences and presented both points of view to the class the next day. Rather than arbitrating this debate, Simpson suggested that the entire class explore the issue.

Like Iwasyk, Simpson described herself as modeling in whole group discussions ways of speaking that she hoped her students eventually would adopt in their interactions with one another without her presence:

When teachers start using (collaborative conversations) to help students think critically about the predictions, observations, and inferences, the dialogues usually tend to be dominated by teacher questions with student responses. As students become accustomed to the process and as they practice logical thinking and mental debate of the ideas, they will start asking questions. The student questions need to be answered with a teacher question that helps them move along in the logical reasoning. As the process evolves, other students will become involved and some of the best reasoning dialogues will involve students only, bypassing the teacher entirely. This is a very valuable learning situation in which students talk and reason with each other. They are actively thinking and have matured in their ability to reason logically so they can move to conclusions without the crutch that the teacher questions provide.

Simpson expressed pleasure in the ability of the second-year physics students to engage one another in collaborative dialogues this early in the school year. She attributed this to their extensive experiences with these ways of speaking during their first year in studying physics. One of her goals was to help students learn how to explore a topic by asking questions of one another without needing much assistance from her within the contexts that she established. Like Iwasyk, she wanted her students to learn ways of speaking that helped them make progress in their thinking as well as to learn the particular science content that was the topic of the lesson. An example of Simpson’s questioning is provided under Teacher Questioning Assertion 2.

Teacher Questioning

We have formulated the following assertions to describe common aspects of teacher questioning across these cases.

Assertion 1: We elicited student thinking by asking questions that develop conceptual understanding.

Although styles of questioning differed among us, we shared the goal of developing conceptual understanding through guided discussions. A key aspect of such questioning is eliciting students’ experiences. Also important is diagnosing and refining student ideas.
Eliciting Students’ Experiences. Kurose frequently began the day by talking with her first grade students about their moon-watching experiences. She identified several questions that she used for these conversations about the moon. These included:

Initial questions:
- What can you tell me about the moon?
- Please draw a picture of the moon.
- Where can you see the moon?
- When can you see the moon?

On-going questions:
- Where did you see the moon?
- How high in the sky was it?
- When did you see it?
- What kind of moon did you see?
- Please draw what you saw.
- Are all the drawings the same?
- Why do you think some are different?

Through such questions, Kurose helped her students build their knowledge in a context in which they could share their thinking with family and friends at home as well as at school. These were not test questions but rather questions that students could answer according to their own experiences. The many discussions of these observations provided a firm basis upon which the students could build a conceptual understanding of the changing phases of the moon. An example of such discourse in Kurose’s classroom is included under Student Assertion 2.

Diagnosing and Refining Student Ideas. Simpson often began units in high school physics with a written diagnostic question that the students considered informally. She identified questions that she often asked during such initial activities as follows:

- What do you think might happen?
- What experiences have you had to support your idea?
- Does that always happen?
- What might be some reasons why … would not happen?
- What other possibilities might you suggest?
- Who has a different idea about what might be happening?

She wrote the students’ ideas on the board or overhead projector so that all could see them and think about arguments in support or not. Sometimes she did a demonstration or the students worked in small groups to investigate what happened. During discussion of these activities she frequently asked the following kinds of questions:

- What is your evidence for that idea?
- What was your observation?
- What might you infer from that observation?

Simpson typically brought a unit to closure with repeated invitations for students to question the apparent consensus and would reopen the discussion if necessary. She frequently used a form of the following questions:

- Does it make sense that…?
- Do we all agree that…?
- Are we all clear that…?
A long wait time (Rowe, 1986) was also common after such questions, while Simpson provided opportunities for students to risk raising issues that they still found confusing. An example dialogue from one of Simpson’s physics classes is included in the next section.

**Assertion 2:** We elicited student thinking by asking students to make their meanings clear, to explore various points of view in a neutral and respectful manner, and to monitor the discussion and their own thinking.

During discussions, our questions often resembled questions that a high school physics teacher, Jim Minstrell, described metaphorically as “reflective tosses” (van Zee & Minstrell, 1997a,b). This teacher envisioned his questions as “catching” the meaning of the students’ utterances and “throwing” responsibility for thinking back to the students. van Zee and Minstrell identified three types of such questions, which also were evident in the case studies reported here:

1. **Clarifying, Exploring, and Monitoring Points of View.** In talking about the moon with fifth graders, Wild asked students to think about why we see the moon. A student gave a very brief response, to which Wild responded with a request for clarification:

   ```plaintext
   | S: | The sun.         
   |    | reflective | T: How does that work? Tell me more about it. 
   | toss | S: | The sun, it gives light, and it gives light on the moon, and we can see the surface of the moon because of the light. |
   ```

   This unit of analysis (student/teacher/student) highlights how a teacher question influences student thinking. In this case, the teacher’s question prompted an elaboration that clarified what the student meant.

   We also asked questions to encourage students to consider various points of view. We tried to acknowledge students’ contributions in a neutral manner. By neutral, we mean without labeling particular views as right or wrong. Our intent was to model respectful interest in what each student was saying without signaling an evaluation of an utterance’s correctness with respect to scientists’ conceptions. For example, small groups of Wild’s students were arranging themselves in positions to act out the locations of the sun/moon/earth system for particular phases of the moon. For the first quarter moon, the student playing the role of “moon” had to think about on which side of the “earth” to stand. Wild engaged the students in thinking about this for a first quarter moon:

   ```plaintext
   | T: | Who could come up and help us decide? [S4]? |
   |    | reflective | S4: | . . . if you were over on this side of [S13], it would be a third quarter moon. |
   | toss | T: | What we want to know is, why are you choosing this as the correct position? |
   |    | reflective | S4: | Because if the sun shines on the moon it will only see the first quarter of the moon |
   |    |    |    | it shines on here (?) and it’d be in the right position. |
   |    | reflective | T: | Then can you explain why the “earth” would see the first quarter? |
   | toss | S4: | Because the sun shines on this side and not on this side. |
   ```

   Reflective tosses can overlap in three-turn sequences similar to a chain of IREs (teacher Initiation, student Response, teacher Evaluation) (Mehan, 1979). In this case, the tosses elicited support for a particular point of view.

   Another form of a reflective toss helped students become aware of their own thinking in the context of a discussion. For example, Wild sometimes took a poll to make visible the spread of
opinions in the class. When the students were discussing on which side of an “earth” a “moon” should stand, she invited all members of the class to express their opinions:

S17: Wouldn’t it be the right side?

T: ... You’re not sure, it doesn’t sound like, [S17]

Okay, how many think this is the first quarter?

Ss: (some raise hands)

By polling the class, she shifted the “authority” for judging answers from the teacher to the students; they had to make up their own minds rather than being told what to think (Russell, 1983). Conducting a poll also made evident how many students thought one way versus another. Such information can help a teacher decide what to discuss next. Although we would begin our lessons with definite plans in mind, we frequently modified these depending upon students’ responses to such on-going assessment questions.

Making Sense of One’s Own and the Group’s Ideas. Rather than presenting physics principles directly, Simpson hoped to have her students construct these through making sense of their own ideas. For example, she and her students were studying forces acting on static objects. They already had discussed forces acting on a book at rest on a table in a manner similar to that described by Minstrell (1982). The book had a weight of 15 Newtons (a Newton is a unit of force in the metric system). Now they were considering the forces acting on a book hanging from a string. A physicist would draw the same force diagram for these two situations to represent that the string is pulling up, or the table is pushing up, with a force equal in magnitude but opposite in direction to the downward pull on the book by the earth. The students, however, found the new situation challenging. A student had drawn her arrow pointing down longer than her arrow pointing up. Simpson hung the string and book from a spring scale. The scale read 15 Newtons. The student realized that the arrow pointing up should be the same length as the arrow pointing down. She described her puzzlement about the situation as follows:

SF2: Ok. Wait. I, I understand that like, the um that that the force of gravity is pulling 15 Newtons, because we measured that and then the string is the same, because the book is not moving, it’s not going farther down. It’s obvious that the string is, it has the same pull, but I FEEL like it shouldn’t. I mean I FEEL like it doesn’t make sense. I mean it makes sense, but I feel like there should be, I don’t know, there are some things like when I first, when we, when I drew this, before we started, before [S1F] gave you, um, her measurements or whatever when I first drew it, I drew that my, the pull going down was more.

Simpson asked a question to clarify what SF2 meant:

T: More than the pull up?

SF2: Yes, but then again, now that I think about it, this makes sense, so I guess that’s right. I guess I’m just thinking out loud.

Simpson then asked the student to assess the current status of her thinking:
T: So what makes sense now?
SF2: That the pull is equal because the book is not moving.
(undercurrent of students talking with one another “are they equal?” can be heard)
T: Does that make sense to you?
SF2: Yeah

This student then wanted verification that she was right. Another student joined her in this quest
for certainty based on the authority of the instructor:

SF3: I have a question
SF2: That’s right, right? That’s what we’re concluding?

SF3: Ok, is it correct to say that if something is not moving,
the forces around it must therefore be equal?
Because if, it has to, the bottom,
the bottom has to be 15 Newtons on both sides,
because if it were unequal, it would be moving
Is that, is that correct?

Simpson turned the question of correctness back to the students for their judgment:

T: What do you guys think?
Ss: Yeah, Yeah
T [SF1]
SF1: Yeah
T: Yeah?
SF1: Yeah!
SM1: Yeah
SF2: Completely rational
(general laughter)

After Simpson agreed with these judgments, the two students then re-asserted their conclusions:

S2F: If something is not moving, the forces must be equal.
S3F: If something is not moving all, the forces must be equal around it,
because if the forces were unequal, therefore it would be moving,
something would be stronger, it would have to be, you know.
(undercurrent of student comments to one another)

These students had just articulated Newton’s First Law, based on their own reasoning, rather than
referring to something memorized from a textbook. This summary prompted [SF2] to ask a new
question about the book hanging on the string:

S2F: Well, are there forces on the sides?

Simpson responded by inviting the student to explore various possibilities:

T: What would be exerting the forces from the sides?

In this episode, a student commented upon the difficulty she was having in making sense of a
situation. There was a disparity between how she had “felt” something should be and what she
now thought. In the process of reflecting upon her thinking in progress, she articulated the essence of Newton’s first law but she was not sure of this. She wanted confirmation of this conclusion. Once she felt confident of the conclusion derived from consideration of vertical forces (“if something is not moving, the forces must be equal”) she applied it horizontally (“are there forces on the sides?”). Rather than providing an answer, Simpson responded to this unexpected question with a question that began an exploration of various possibilities.

In an interview with van Zee after this session, Simpson described her teaching as follows:

I see this class about being about thinking . . . when [SF2] was talking out loud, she really wasn’t looking for me to help her as much as she just needed to hear herself say it, and as she was talking, she was thinking and was able to sort out the ideas just by hearing the things she was saying and from the struggle with those ideas. We call this “muddling.” First I know that they’re actively thinking about it rather than just trying to sit there and get it by osmosis. It appears then when they are talking about the ideas they can make logical sense of them if they put together all of the pieces that have been provided.

One of the students commented about the learning that occurred in this approach to instruction:

And you learn from your questions. She makes us figure out what we’re asking, if it’s right or wrong but we have to decide if it’s right or wrong. You know she doesn’t really tell us. She makes us figure it out.

Not all students, however, appreciated this approach to instruction. In an interview with van Zee after the above discussion, [SF3] commented:

It’s always an irritating thing when you ask somebody a question, and they answer it with a question because eventually you want an answer, and since she is the teacher and in a position of authority and she is the one who is supposed to be finalizing our views, at least for the moment, it can sometimes be a little ambiguous.

Simpson guided discussions in ways that welcomed students’ reflections upon what they had found confusing and how their thinking had changed. Through such dialogues, major ideas emerged, voiced in ways that the students could understand. Even when the students had come to consensus on a particular issue in a particular context, a student could raise new questions that led to discussion of a related topic. Not all students, however, appreciated learning this way.

Assertion 3: We elicited student thinking by practicing quietness as well as reflective questioning.

Sometimes we chose to “practice quietness” rather than questioning. Practicing quietness is an intentional act that requires active restraint. It has three components: wait-time, attentive silence, and reticence. Wait-time was evident in the long pauses that occurred occasionally while we waited for a student to speak or before starting to speak ourselves. Attentive silence involved listening carefully to what students said, particularly during a series of exchanges among themselves. van Zee, for example, listened intently during the student-generated inquiry discussion presented under Student Questioning Assertion 3. Being reticent means providing information only as needed and encouraging students to figure things out for themselves rather than providing explanations. Rather than telling her students what she knew about Newton’s first law of motion, for example, Simpson listened closely as they articulated what they thought to be
the case. Iwasyk encouraged her students to share their knowledge about shadows rather than displaying her own.

Discussion

We constructed the chart in Table 1 to help ourselves think about ways of speaking that seem to be associated with various philosophies of teaching and learning. On the left side of the chart, for example, lecturing represents didactic “teaching by telling” in which a teacher makes the decisions about what topics to teach, textbooks to use, tasks to be attempted, time schedules to be met, and tests to be taken. Ways of speaking toward the right side of the chart represent “learning through inquiry.” Entirely off the chart to the right would be “learning through inquiry in everyday life” in which individuals must make decisions for themselves about what topics to explore, resources to use, tasks to try, pace to proceed, and ways to assess their own learning. Because we share the goal of preparing students to engage in learning through inquiry in their everyday lives, we have focused upon the ways of speaking toward the middle and right side of the chart: guided discussions, student-generated inquiry discussions, and peer collaborations.

Charts such as Table 1 present a simplified view of very complex processes. The realities of our classrooms are messy: we shift among all five ways of speaking frequently. During class, for example, we may initiate a recitation to review what the students have studied to date, guide a discussion while diagnosing and refining students’ ideas about the current topic, listen quietly should students begin to generate and explore their own inquiries, and move students into small groups at a point when they seem ready to undertake some investigations. Conversely, we may begin with peer collaborations and then bring the whole group of students together to reflect upon their findings. In both contexts, we may decide to deliver information in mini-lectures at moments that seem appropriate according to what is happening and what we intend students to be learning.

Although the lines between columns suggest sharp demarcations, we view this as a continuum along which teachers move according to their beliefs, intents, and circumstances. More traditional teachers more often use the ways of speaking delineated on the left side of the chart; less traditional teachers more often use the ways of speaking delineated in the middle and right side of the chart. We offer our case studies as examples that might be helpful for teachers interested in shifting their teaching practices toward the right in the chart, which we perceive to be toward the more inquiry-based approaches advocated in reform documents (NRC, 1996).

Below we summarize assertions based on common themes across our case studies. We also comment upon our students’ learning, dilemmas we faced while teaching, limitations of the studies, directions for future research, and implications for professional development practices.

Summary of Assertions about Student and Teaching Questioning

Our first assertion about student questioning seems obvious: our students asked questions when we invited them to do so. For example, we recorded questions that students asked while constructing KWHL charts, brainstorming, and listing issues they were still pondering at the close of a discussion. Apparently many teachers choose not to issue such invitations, however, as studies typically find that students rarely ask questions (Dillon, 1988; Lemke, 1990). A few teachers have documented ways in which they foster student questioning, however. Pearce (1993, 1999), for example, has written about ways he has nurtured inquiries among his students. Gallas (1995) documented primary children’s questions and ways in which she built upon these in designing curriculum. We view our case studies as contributing to this literature about student questioning written by practitioners reflecting upon their own science teaching practices.
Our second assertion about student questioning also seems straightforward: our students asked perceptive questions during conversations about familiar contexts in which they had made many observations over a long time period. This confirms earlier findings by Miyake and Norman (1979) that people need to know something about a topic before they can formulate good questions. Kurose’s first-grade student, for example, was capable of wondering what a waxing crescent moon looks like on the equator because he was knowledgeable about the phases of the moon, the global representation of the earth with northern and southern hemispheres bounded by the equator, and the use of the equator in thinking about the orientation of a crescent moon at different locations on earth. Such questions from a first grade student support claims that children are capable of highly abstract thinking in contexts in which they are knowledgeable (Metz, 1995).

Our third assertion about student questioning states that students asked questions when we created comfortable discourse environments within which they could try to understand one another’s thinking. We documented such student-generated inquiry discussions in both structured and spontaneous contexts. Like Gallas (1995), we viewed these multiple student/student/exchanges as occasions when the students made major progress in their thinking. Like Hammer (1995), we were willing to tolerate conversations during which students made statements that were not in accord with scientists’ views while they struggled to make sense of what they were thinking.

Our fourth assertion about student questioning involves peer collaborations. Students asked questions of one another as they worked together in small groups without the teacher present. From tapes of small group conversations, we identified instances when students used ways of speaking with one another that we had modeled in whole group discussions, such as asking questions that moved the thinking forward while mentoring a classmate. We also identified instances of students questioning one another as they collaborated in exploration of issues they had formulated. These queries often prompted deeper reflection (e.g., how did you determine that it gets longer?), similar to those documented by Hogan et al. (2000).

Our assertions about teacher questioning reflect our philosophical orientation toward constructivist approaches to instruction (Fensham et al., 1994). We asked questions to develop conceptual understanding. By eliciting students’ experiences, we activated their prior knowledge both so that they could build upon their initial ideas and so that we could be aware of what these were. In particular, we were seeking useful intuitions through which students’ competence could be expanded as we diagnosed and refined their ideas (Smith, diSessa, & Rochelle, 1993).

We guided discussions by asking students to make their meanings clear, to explore various points of view in a neutral and respectful manner, and to monitor the discussion and their own thinking. These functions of teacher questioning had been identified in a prior study of questioning in a high school physics classroom (van Zee & Minstrell, 1997a,b). We found them to be critical in our efforts to engage our students in argument and explanation as recommended in the National Science Education Standards (National Research Council, 1996).

We also chose to practice quietness as well as reflective questioning. By this we mean more than a long “wait-time” (Rowe, 1986) before and after students speak. Also important are listening attentively and being reticent about one’s own knowledge while assisting others in expressing theirs. Abell and Roth (1995), for example, noted that “we often found it difficult to listen and make sense of student ideas during the course of the class discussion” (p. 71). Gallas (1995) described herself as a “teacher who had to learn to be quiet in Science Talks” (p. 30). Schaible and Rhodes (1992) proposed a rule: “enforced silence of the instructors” (p. 103) that should be followed in creating an environment for student exploration of complex issues at the college level. Our experiences confirm the importance of being quiet in order for students to think.
**Student Learning**

Many studies of teacher questioning have focused upon the relation between the cognitive level of teacher questions (Bloom et al., 1956) and student achievement. The results of such studies have been mixed (Brophy & Good, 1986). We have not attempted to demonstrate that our students achieve at higher levels than students in other classrooms. As teachers reflecting upon our own practices, we consider such comparative studies to be both impractical and inappropriate. We have, however, collected and reflected upon evidence of our students’ learning, both about science and about effective ways of speaking.

The on-going discussions characteristic of our classrooms provide formative assessments of our students’ progress. When we invite students to ask questions, for example, we are inviting them to display the knowledge they have available to formulate a question. “How can the moon be rising in the morning?” for example, provides evidence that this first grade questioner had learned that the moon was visible during the day and also knew that this was not expected behavior. Many adults, for example, only expect to see the moon at night.

Questions that emerge during guided discussions provide evidence of our students’ growing abilities to converse thoughtfully by explaining their ideas and asking questions of one another. The first-grade student who asked what a waxing crescent moon looks like on the equator demonstrated more than his knowledge about the moon and representations of the earth. He also demonstrated that he had learned to listen carefully to a discussion and to generate a question that articulates a missing piece. Through such questions students learned that they could raise issues of interest to their teachers that warranted exploration. Some also learned how to ask questions to help others, and sometimes even themselves, to think through something that initially was not well understood.

The transcript of a conversation about the moon among college students demonstrated their growing competency in collaborative inquiry. The questions they asked themselves and one another revealed not only their detailed knowledge of the moon’s apparent shapes and motions but also their ability to reflect upon their assumptions, claims, and warrants in constructing scientific arguments.

One of the prospective teachers wrote a reflection about what she had learned during the moon studies:

> What I’ve learned is that teachers play a great role in classroom inquiry by providing students with the means to promote inquiry learning. Students do formulate questions and answers to their questions, but do so through a teacher who helps them engage in hands—on activities, explore and self-discover, by guiding them in the right direction. In the beginning of the semester, I was wary about how this method could work in a classroom. Now, although I have a lot to learn, I understand the basic elements and what students have to gain from inquiry-based teaching and learning.

By participating in a sustained inquiry herself, she had learned about this approach to teaching.

**Dilemmas**

Teachers face many dilemmas. Those who primarily lecture must decide which topics to include, in what sequence, and in what ways. Teachers who primarily conduct recitations must decide what questions to ask to move through a planned agenda. Teachers who primarily guide discussions must decide how to respond to the students’ thinking. Teachers who foster student-
generated inquiry discussions and peer collaborations must decide how to create environments in which these can flourish.

One of the authors, Wild, and a colleague discussed many of the dilemmas teachers face in shifting toward more inquiry-based practices. Wild’s colleague had been engaging two fifth-grade classes in watching the moon for several months. Their plan was for Wild to demonstrate two culminating lessons with one of the classes while her colleague watched and then for the colleague to teach these lessons with the other class. During the first lesson, there had been no substantive student questions. Wild attributed this to the constraints imposed by her own questioning style that day, which had been a series of “lower level” questions. She saw these as necessary for achieving her goal of leading the students through the logic of the model for explaining the moon’s changing phases. On the second day, however, Wild had welcomed student ponderings in the context of talking about rising and setting times for the various phases. Her colleague, however, expressed bewilderment about the more open-ended structure of the second day’s session when Wild had explored a number of questions such as the one reported here in support of our second assertion about student questioning. The colleague chose to implement only the first day’s guided development of the explanatory model. She considered the second lesson to be disorganized and incoherent and did not perceive the students as learning enough to warrant spending time on it.

In a later conversation about the lessons, Wild’s colleague articulated the dilemma posed by unexpected student questions: “Do I stay now and discuss this and spend time on what these students want to talk about now or do I get through the lesson?” She and Wild summarized some of the factors that influenced their decisions in responding to student questions. Most important is the intent of the lesson and how closely related the student’s question is to the objective of the lesson. Sometimes they can supply factual information readily without much disruption but if the student’s question is best answered through questioning then they consider many factors. These include how much the rest of the class seems interested, how knowledgeable they themselves are about the topic and about teaching the topic, and how much time is available until the end of the hour and the end of the term. Also important is whether they can understand the question.

The need to “get through the lesson” can conflict with shifting toward science “as argument and explanation” as advocated in the National Science Education Standards (NRC, 1996, p. 113). In reflecting upon discussions during a fifth grade life science lesson, for example, Abell and Roth (1995) acknowledged trying to “funnel students to the right answer in our understanding of the scientific model. We accepted all ideas, but did little to facilitate a discussion in which ideas could be compared and evaluated” (p. 71). If, when, and how to do the latter are major dilemmas in guiding discussions.

**Limitations**

The assertions presented here apply only to the authors’ classrooms at the time of these studies. The validity of the case studies is limited by the subjective process through which we identified videoclips for analysis on the basis of our impressions that productive discussions were occurring. Although we did not follow a formal procedure for co-operative inquiry (Heron, 1996), we engaged in some of the practices recommended for increasing validity such as recycling through phases of action and reflection, both individually and collectively. The shift in authorship of the case studies increased the likelihood that the interpretations were accurate reflections of the teachers’ perspectives. However, self-reflections are inherently biased and likely myopic. Other researchers might well find different questioning practices to explicate in these classrooms.
Directions for Future Research

Through the case studies, we have documented ways of speaking that foster our students’ questioning and thinking about science topics. Each case is a small window through which we have invited others to look into our own worlds; deepening the analyses of existing cases and developing additional cases would widen the view. Of particular interest to several of us is documenting changes in our students’ ways of speaking during the school year, not only in their questioning but also in their ability to engage in discourse that facilitates the learning of their colleagues. The nature of such collaborative discourse seems to involve quietness in addition to reflective questioning. We plan to explore further the roles of several components of quietness that we have identified: longer wait times; attentive silence; and reticence. We also find intriguing the opposite of quietness, the phenomenon of “cacophony” in student-generated inquiry discussions. In addition, some of us are interested in broadening the focus to the nature of collaborative dialogues at different stages of instruction within a unit. Several members of our group may build upon their research experiences in this project to undertake studies of other aspects of their practices such as their approaches to teaching reading, writing, and social studies.

Implications for Professional Development

Our intent has been to contribute to the science education literature some specific examples of student and teacher questioning that we believe may be useful to teachers interested in moving toward more reflective practices. We also have attempted to construct a set of assertions about student and teacher questioning that reflect our insights and experiences as practitioners. We believe that reading such assertions, with accompanying examples, can help interested teachers and will contribute to the apprenticeship that may be necessary for appropriating the complex questioning practices characteristic of inquiry curricula (Roth, 1996).

In initially designing this project, the university researcher assumed that research can become more directly applicable to improving science teaching if teachers participate in the formulation of research issues, if data are collected in the midst of on-going instruction, if teachers and researchers collaborate in the analyses, and if findings are communicated in narrative case studies that provide specific examples of approaches to science teaching that are being advocated in reform documents. Rather than focusing only on content (e.g., students’ understandings of particular topics) or only on discourse (e.g., cognitive level of questions asked), the case studies address communicative issues within particular subject matter contexts. Rather than reporting a researcher’s critical assessment of inadequacies in instruction, the case studies present positive examples of what students and teachers are attempting to accomplish through their science discourse, written from the perspectives of the participating teachers. In addition, the project provides an example of the shift in practice for a university researcher from conducting research oneself with teachers to facilitating research conducted by teachers in their own classrooms. Such a shift seems imperative for fostering professional development of teachers by enhancing their normal practices through collaborative action research (Feldman, 1996).

We have developed ways of embedding our papers in materials that can be used in professional development settings. The papers document positive aspects of our questioning practices that we wish to explicate. The teaching materials provide a structure for communicating our findings in courses, workshops, and conferences for teachers. We currently use the term “case study” to refer to the following (a) selected data such as excerpts from a transcript of a discussion or copies of student work, (b) a set of specific questions to prompt discussion of
these data, (c) a set of general questions to prompt discussion of relevant issues, and (d) a paper authored or co-authored by a teacher in whose classroom the data were collected. In contrast to teaching cases that provide background information and then pose a dilemma, our case studies provide data and then invite interpretations. We also provide access to the teacher’s interpretation through the paper.

Reforming science education means providing opportunities for conversations about science learning at conferences as well as fostering conversations about science content in classrooms. We engage conference participants in inquiring about our inquiries in ways that they can formulate questions and explore interpretations with us during a session. On an evaluation for such a session at a National Science Teachers Association conference, a participant wrote:

As a high school science teacher, it was fascinating to discuss science-related classroom teaching issues with bright, reflective educators, especially of elementary-age kids. The dying out of inquisitive sparks of interest from 1st grade to high school… this is immensely useful (though sobering) to discuss…

Such conversations seem to us to be a useful step toward reform of science education.

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