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Relation between Teacher and Student Questioning during Conversations about the Moon

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This study was part of an on-going research program to analyze student and teacher questioning during conversations about science. Data sources included audio-tapes of discussions in fifth grade classes in a suburban parochial school, lesson plans, copies of student written work, and taped conversations with two collaborating teachers. A less experienced teacher observed a more experienced teacher conduct several discussions about the phases of the moon. During the first discussion, the more experienced teacher moved through a series of questions that she had prepared in a written lesson plan. During a subsequent discussion, she allowed students to raise issues that she regarded as tangential. The frequency of student questions was greater during the second discussion than the first. When conducting her own discussion about the moon, the less experienced teacher chose to use the more structured approach. Both teachers experienced dilemmas in deciding between asking questions that followed the students' leads in thinking and asking questions that moved their own agendas forward.

RESEARCH QUESTIONS

This study is a collaborative effort to develop case studies of questioning processes for use in teacher education programs. We present dialogues that can be used in discussing the following issues: How does a teacher set up a certain progression of thought and then move through that agenda by questioning? How do students initiate comments and questions that express their own thinking? What is the relation between student questions and teacher questions? What dilemmas do teachers face in maintaining their planned direction for a lesson while enabling students to pursue their own paths to understanding a topic?

Questioning is a central component of classroom discourse (Bellack et al., 1966; Cazden, 1986, 1988; Dillon, 1988; Lemke, 1990; Sinclair & Coulthard, 1975) and of interactive dialogues that develop student thinking (Cobb, Wood, & Yackel, in press; Clement, 1993; diSessa et al, 1991; Hall, 1990; Moschkovich, Schoenfeld & Arcavi, 1993; Pea, 1991; Tharp & Gallimore, 1988). Many researchers have focused specifically upon teacher questioning (Carlsen, 1991; Collins & Stevens, 1982; Dillon, 1978, 1985, 1988a; Gall, 1984; Graeser, 1990; Hunkins, 1989; Lowery, 1980; Sigel & Saunders, 1979) or upon silences associated with questioning and answering (Rowe, 1986; Tobin, 1987). Other researchers have investigated the nature of student questions and developed ways to help students formulate more and better questions (Cazden, 1970; Dillon, 1988c; Good et al., 1987; Hunkins, 1976, 1987; Palinscar & Brown, 1984; Scardamalia & Bereiter, 1992; Suchman, 1961; van der Meij, 1986).

This study is part of an on-going research program to analyze student and teacher questioning during conversations about science (van Zee, 1990; van Zee, 1992). In an earlier project, the first author worked with a high school physics teacher, Jim Minstrell, to develop a framework for analyzing teacher questions during class discussions (van Zee & Minstrell, 1990, 1991b). The current study examines whether this questioning framework is useful in a different context, conversations about science in an elementary school classroom.

The questioning framework was based upon two metaphors that Minstrell used in thinking about class discussions: networks and negotiations. The framework included questions called "nodal queries" and "reflective tosses." "Nodal queries" are key questions that represent the main moves in a teacher's instructional agenda. Minstrell envisioned these key questions as a series of conceptual "nodes" to which he returned after venturing down paths that explored student thinking. "Reflective tosses" are more spontaneous questions that "catch" the meaning of the student's prior utterance and "throw" responsibility for thinking back to the students. Minstrell used such questions to develop shared understandings with his students (Minstrell, 1989). The framework grouped such questions into three categories based upon three processes that are important in negotiations: making meanings

clear, considering alternative points of view in a neutral manner, and monitoring the discussion and one's own thinking. In response to such teacher questions, students typically expressed their own ideas rather than recited textbook knowledge. Such classroom talk was called "reflective discourse" (van Zee & Minstrell, 1991a). The questioning framework also was descriptive of questions asked by Minstrell's colleagues, two experienced mathematics teachers whom he coached to teach high school physics (van Zee, Corey, Minstrell, Simpson & Stimpson, 1992). The study reported here extends this research by examining whether the framework is descriptive of questions asked by other teachers in conversations about science with younger students.

Students rarely ask questions in traditional classrooms (Biddulph, Symington & Osborne, 1986; Dillon, 1988b; Good, 1987; Minick, 1991). Recent reform movements have advocated increasing student questioning in many contexts. If student questioning is an instructional goal, we need to know more about the phenomena we are attempting to promote. This study contributes to the growing body of data on student questioning, examines the relation among the nature and frequency of student questions and the nature of teacher questions during two class discussions, and analyzes the interactional contexts into which student questions emerged in these settings.

In this study, we present the reflections of two collaborating teachers, Judy Wild and Peri Flanagan, and a university researcher, Emily van Zee. In a series of conversations, we discussed two lessons that Wild conducted to demonstrate inquiry techniques for Flanagan. Although Wild had started both lessons with a clear plan of action, she made different judgments about maintaining her intended direction. During the first discussion, she moved through a series of questions that she had prepared in a written lesson plan. During the second discussion, she allowed students to raise issues she regarded as tangential. Later in the school year, Flanagan chose to conduct the first lesson but not the second. The study documents dilemmas these teachers faced in deciding what to say and do next during these class discussions.

The subject matter context of the study was naked-eye astronomy. Both children and adults experience difficulty with the complex thinking required in developing a model for the sun, earth, and moon system (Chastain, Oberem, & McDermott, 1993; Foster, 1993; Nussbaum, 1979; Schnepps, 1986). Traditional instruction frequently leaves intact naive notions with which students begin their study of astronomy. In a recent study, for example, about three fourths of the students answered a question about the phases of the moon incorrectly both before and after instruction (Lightman & Sadler, 1993). Students must make a major conceptual leap to connect what they see outside (a sun and moon that appear to move in similar ways across the sky as viewed from a fixed earth) with what they see in class (a "sun" that stays fixed while a "moon" and "earth" rotate in complicated ways). Through class discussions and small group activities, Wild engaged her students in working through what bodies move when, where, and how in both frames of reference. In this study, we did not assess student learning either before or after the lessons nor have we systematically documented student difficulties evident in these conversations. We have chosen instead to focus on the *communicative moves* involved. However, our analysis provides specific examples of ways in which such conceptual issues emerge in the context of interactive dialogues.

METHOD

This study was conducted in the tradition of ethnography of communication (Erickson, 1986; Hymes, 1972, 1982; Jacob, 1987; Philipsen, 1977, 1982, 1992). Its focus was the relation between teacher and student questioning during two science lessons in an elementary school classroom. Our analysis primarily involved interpretations of teacher and student questions in transcripts of class discussions.

In identifying utterances as questions, we adapted a taxonomy of questioning suggested by Saha (1984). We considered questions to be utterances that use an interrogative word (who, what, where, when, why, how ...?), that exhibit an inverted word order (did you..?), that end in a rising intonation (you did?), that use a tag (isn't it?) or an interrogative marker (not observed), or that use a disjunctive form (you did or did not..?). In addition,

we analyzed embedded questions and some alternative forms. In analyzing teacher questions, we focused upon two types, those that represented the next step in the teacher's agenda and those that explored student thinking. We did not analyze many other kinds of teacher questions such as rhetorical questions to which the teacher does not expect a response. In identifying student questions, we did not include declarative statements with a rising intonation that seemed to indicate a request for validation of the student's response from the teacher.

Participants included fifty students in two fifth grade classes in a suburban parochial school, two teachers with different experience in teaching science, and a university researcher. The two teachers had worked closely together in several contexts before the start of this study. The less experienced teacher, Peri Flanagan, had been teaching for five years but this was the first year in which she was responsible for teaching science. The more experienced teacher, Judy Wild, had been teaching science as a process of inquiry for more than fifteen years. She and the university researcher, Emily van Zee, had both worked as staff members in special physics courses for in-service teachers at the University of Washington (McDermott, 1990, in press). Wild also had been a student in physics courses for pre-service teachers that were the setting for Minstrell's doctoral research (Arons, 1972; Minstrell, 1978).

Data sources included audio-tapes of instruction, copies of lesson plans and student papers, and audio-taped "research conversations." The research conversations involved the active sharing
of thought among the co-authors rather than the question and answer structure typical of a researcher interviewing subjects.

We analyzed transcripts of the lessons and of research conversations about the lessons. As discussed below, Wild prepared narrative analyses of her lessons for use in programs for teachers. In addition, we identified teacher questions and examined whether they could be grouped according to the framework developed in the high school context. We also identified student questions, compared their nature and frequencies during the two lessons, and examined the interactional context within which they had been

asked. We also summarized the teachers' reflections about dilemmas they had experienced in conducting the discussions.

NARRATIVE ANALYSES

We define "narrative analysis" below and summarize the context of its use in this study. Then we include excerpts from narrative analyses prepared by Wild for teachers.

Definition of a Narrative Analysis

We use the term *narrative analysis* to refer to a transcript that has been edited and annotated to assist interested teachers in interpreting the dialogue. Our narrative analyses are intended for use in teacher education programs to provide "real" classroom contexts for discussions about discussions. They are not scripts for teachers to follow but rather *examples* of interactive dialogues. They show ways in which a teacher helped students construct a conceptual model through an intricate series of questioning exchanges. Instead of telling answers, the teacher asked questions to guide student thinking. Through such questioning, a teacher can provide experiences that help students "formulate questions for themselves so they can clarify their thinking and become more consistent in their reasoning."(Wild, 1989, p.26).

We present below excerpts from narrative analyses prepared by Wild for two lessons about the phases of the moon. Wild based the lessons upon curriculum she had used at the University of Washington and elsewhere. The students acted out arrangements for various phases in activities similar to those described in *Where is the Moon?* (ESS, 1971) and *Astronomy Activity Book* (Schatz, 1991). In planning the lessons as a demonstration for Flanagan, Wild had considered the following questions: How do you implement the inquiry technique and what questions do you ask? How do you help students utilize the observations and facts they have accumulated in order to facilitate conceptual development?

Narrative Analyses of Two Lessons about the Phases of the Moon (by Judy Wild)

At our school, we are following guidelines from the National Science Teachers Association and David Cox of Portland State University in designing a science curriculum that focuses upon major concepts such as "cause and effect" (Cox, 1989, 1990). For the two months prior to these lessons, the fifth grade students had participated in experiences designed to facilitate understanding causal relationships in diverse contexts. These experiences involved the effects of diet and exercise, the effects of reflection and refraction, the causes of fluctuations in animal populations and disruptions in food chains, and the causes of hurricanes, volcanoes, and rock formations. The students also had been observing the shapes of the moon over these two months and recording their observations on a class calendar.

My objectives for these lessons were to help students incorporate their observations of the moon into our cause-effect conceptual framework and to involve the students in the process of model building. I had arranged with the 5th grade science teacher to have two 45-minute class periods to conduct two lessons. In the first lesson, I planned to begin the process of model building and to help students use their observations of the moon phases to explain how the relative positions of the sun, moon, and earth caused these phases. In the second lesson, I planned to continue model building so that the students could not only explain the cause of the moon phases but also use the relative positions of the sun, moon, and earth to predict where and when they could look for the various phases.

The first lesson went as planned; however, in the second lesson, student initiated questions and comments were explored and an additional class period of 30 minutes was needed to complete the lesson. Following is a synopsis of the activities and discussion from these lessons. [The transcripts below have been heavily edited. ... indicate omissions.]

Lesson 1: We began by talking about the nature of light from the moon and reviewing the students' observations:

T: We want to focus on "cause and effect." Here you're showing me an effect, you're showing me what the moon looks like over these months. What's the cause of our seeing the moon? Why do we see the moon? S1?

S1: The sun.

T: How does that work? Tell me more about it.

S1: 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.

T: Exactly...

[discuss objects that emit light versus those that reflect light]

T: ...the moon...reflects light from the sun...
Let's take a look at the moons that you drew here.
These are the different shapes...as you saw them?
And you started back in November...
Can someone tell me something about your observations? S2?

S2: Well, I've kind of been watching the moon change
and I've noticed sometimes that each night it either gets,
the sun's reflection on the moon either gets larger or it gets smaller.
When the light shines on the moon, it like one night it will be a half,
and it's getting smaller, and then the next night it'll be a large crescent,
and then the next night it'll be a small crescent

T: ...Something else, S5?

S5: Well, I've noticed that the moon...changes its patterns...

T: Can you describe a pattern that you have observed?

S5: It starts out with a very tiny crescent and then it becomes bigger until it becomes a half then it becomes bigger until it becomes full
and then it starts shrinking back to half again except on the opposite side
and then it becomes a crescent again and then it disappears

T: Having made those observations, do you feel you could predict
what the moon would look like next week?

I asked the students to make drawings to show their predictions of what the moon would look like in one week and in two weeks and to check at those times to see if their predictions were accurate. (Most were.) Then we talked about times when the moon is visible.

T: ...S2 said that she saw the moon at night time.
Can someone tell me more about the times you saw the moon? S11?

S11: Sometimes you can see it at 3 o'clock or 4 o'clock when you leave school.

...

S8: And sometimes I see it in the morning when I get up.

...

S13: In school one day we were going over this, (I saw it out the window).

S3: Well, I just wanted to comment that one day that I didn't see the moon I looked back on what I wrote the day before and then I looked back on the day before and I followed the same growth pattern, so then I knew what today's was because I followed the same growth pattern back up and up
and more and more and more and you can observe that and then
even if you didn't see the moon that day
then maybe you can make a pretty accurate prediction.

T: ...using the data you observed to make predictions and checking it out is...great.
One, about the times that we see the moon...
And second...what causes the moon to be different shapes
For today's work, I'd like us to look at four of the shapes,
we call these the phases of the moon...I'm going to draw them on the board...
I'd like to have us look at a time when the moon is ...very thin on either side, when you see just the right side lit up,
when you see the whole disk of the moon lit up,
and when you see just the left side lit up...
One thing that we didn't look at when you were looking at the moon...
(was) the angle...between the sun and the moon...for these different shapes. That's what we would like to look at today...
so one thing I'd like to do is review angles...
[review of angles of 0 , 90 , 180 , 270 , and 360 degrees]

Then the students used tennis balls to represent the moon and light from an overhead projector to represent the sun. Their eyes represented the earth. I instructed them to stand and rotate with the "moon" held high in their outstretched arms so they would not cause an "eclipse." When they found the following positions (right side of "moon" lit, left side lit, the entire face lit, and entire face not lit), they stopped and recorded the angles between the "sun" and the "moon." After the students had found and recorded the angles for each phase, volunteers demonstrated these positions. When a student held the "moon" in the same direction as the "sun" so there would be zero degrees between the student's outstretched arm holding the "moon" and arm pointing to the "sun," I sketched this arrangement on the board and labeled it "new moon." When a student held the "moon" so that the right side of the ball was lit and there would be ninety degrees between the student's outstretched

arm holding the "moon" and arm pointing to the "sun," I drew a sketch of this configuration and labeled it "first quarter." Likewise, when the student held the "moon" with angles of 180 and 270 degrees between the student's outstretched arm holding the "moon" and arm pointing to the "sun," I sketched these arrangements and labeled them "full moon" and "third quarter" respectively. We also discussed some reasons for these names for the phases of the moon.

Lesson 2: In this lesson, we reviewed the cause of the phases of the moon and used the relative positions of the sun, moon, and earth to predict where and when various phases could be seen. In the first activity, students worked in groups of three to review moon phases. One student in each group received yellow paper representing the sun; another received orange paper representing the moon, and the third student received green paper representing the earth. I instructed the groups to stand in the positions necessary to demonstrate the moon phases and we discussed discrepancies as they occurred.

After this review, we discussed the apparent motion of the sun and various times based upon this motion. We defined sunrise as the time when the sun is first observed on the eastern horizon, sunset as the time when the sun is observed on the western horizon, noon as the time when the sun is at its highest point in the sky, and midnight as the time between sunset and sunrise when the sun is "directly opposite" its noon position. We used these to describe when and where we can observe the moon.

T: ...think about where you saw the moon, when you saw it. And tell me if you all saw it in the same place, or if you saw it in different places

S2: ...over here and then it moved

T: ...it sounds like you've seen some of the same movements with the moon
as we've seen with the sun...

S2: And when it was over here it was half and when it was over here it was full.

T: ...so it even looked different in different places.
S8, what did you observe about where...

S19: In the morning, I go to where (my bedroom) is, I can sometimes see the moon and then at night I go over into the dining room, or no, the living room

which is on the opposite side of the house, and I look out and I look up, so it's...I think it's made a complete rotation from one side to the other.

T: So...you see it appear to move from one side to the other.
...(let's) figure out when we can go out to see the moon
and where we go to look at it so instead of just going out and seeing by luck
we can figure out just where we would look and when we would look.
...we're going to start with the full moon and we're going to try to figure out where we would see the full moon and at what time.
[Everyone received a yellow paper and an orange paper.]
I'd like the "sun" to be the yellow paper and the "moon" the orange paper.
...I'd like you to take just the yellow paper
and hold it to show where you would see the sun at sunrise.
...now you're going to be the "earth" yourself this time.
...so I'd like you to take the "moon" paper and show me where the "moon" would be. ..okay, what's the direction that the "moon" is in? S10?

S10: (The west?)

T: That's right. So, here's the "sun" in the east and the "moon" in the west.
What do you think the "moon" is doing at this point? S3?

We talked about the full moon setting as the sun was rising and then considered when the full moon would rise and when we might look for it high in the sky. Then the class period was over and we completed the lesson on another day. In the final lesson, we reviewed the times that the full moon rises and sets and is at its highest point. Then the students continued to use yellow and orange paper representing the sun and the moon. By positioning the "moon" in the east, at its highest point, and in the west while locating the relative position of the sun for each of these situations, the students determined the times the moon would be rising, at its highest point, and setting for the new, first quarter, and third quarter moons.

TEACHER QUESTIONS

The narrative analyses in the previous section present the main moves in two lessons about the moon. These moves proceeded primarily by teacher questioning. We examined whether Wild's questions could be described with a framework developed in a previous project by the first author and a high school physics teacher, Jim Minstrell (van Zee, 1990, van Zee & Minstrell, 1990, 1991a,b). This framework is intended for use in thinking about classroom questioning by teachers interested in improving their ability to conduct class discussions.

In contrast to many analyses of classroom questioning, the framework does not involve assessing the cognitive level of teacher questions (Bloom, 1956; Redfield & Rousseau, 1981; Wilen, 1986). It focuses instead upon two closely related processes important in conducting discussions: moving an instructional agenda forward and following a student's lead in thinking. The two main categories, "nodal queries" and "reflective tosses," are based upon Minstrell's metaphors for these instructional actions. In conducting discussions, Minstrell envisioned himself moving through a conceptual network while developing shared understandings with his high school physics students (van Zee & Minstrell, 1991a,b). We discuss below whether similar questions are evident in Wild's conversations about the moon with fifth graders. We are not examining whether these two categories encompass all questions Wild asked, only whether we find in her discourse the presence of such questions.

Nodal Queries

Nodal queries (NQ) are key questions that take the next step in a teacher's instructional agenda. The term "nodal queries" is based upon a network metaphor for the conceptual organization of a lesson. Each main idea is represented by a "node." For example, we classified the following teacher questions as nodal queries:

T: Can someone tell me something about your observations?

T: ...Something else?

T: So having made those observations, do you feel you could predict
what the moon would look like next week?

T: Can someone tell me more about the times you saw the moon?

T: Who could show us what your positions were when you saw the right side of the "moon" lit up?

Primary nodes introduce new topics (can someone tell me something about your observations?). Secondary nodes return to that topic after there has been some discussion (...Something else?). The distinguishing feature of a nodal query is that it leaves behind whatever was last said and moves the thinking on to a new cycle of the same topic(...something else?) or on to the next topic (So having made those observations, do you feel you could predict what the moon would look like next week?). Wild's nodal queries match closely the questions in her written lesson plan and constituted her intended agenda.

Reflective Tosses

Reflective tosses (TOSS) are more spontaneous questions that "catch" the meaning of the student's prior utterance and "throw" responsibility for thinking back to the student (van Zee & Minstrell, 1991b). Reflective tosses typically occur immediately after a student utterance but may refer back to a series of utterances by several students or articulate issues evident in students' actions as well as words. Sometimes the "catch" phrase is implicit rather than voiced; sometimes the "throw" phrase includes many students rather than simply the prior speaker. Subcategories of reflective tosses are based upon a negotiation metaphor. In negotiations, it is important for all parties to make their meanings clear, to consider alternative points of view in a neutral manner, and to monitor the discussion and their own thinking. As discussed below, we identified questions in Wild's discourse that accomplished these functions.

Making meanings clear. Many reflective tosses elicit elaborations of student thinking. These teacher questions are intended to help students to clarify the meaning of whatever the students have just said. In the example below, Wild used a toss to request further information:

NQ T: What's the cause of our seeing the moon? Why do we see the moon? S1?
| S1: The sun.

TOSS	T:	Okay, how does that work? Tell me more about it.
	S1:	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.

Such questioning sequences could be identified as IRE's, teacher initiation (I), student response (R), and teacher evaluation that includes another question (E) (Cazden, 1986, 1988; Mehan, 1979). Another name given teacher/student/teacher patterns of participation is triadic discourse (Lemke, 1990). However, we prefer to shift the unit of analysis over one turn to consider student/teacher/student sequences. We believe that this shifts the focus to ways in which teacher utterances influence student thinking. In the example above, the teacher asked a nodal query that stands alone (what's the cause of our seeing the moon?). Then the student's very short turn prompted a request for further elaboration (Okay, how does that work? Tell me more about it). The resulting student/teacher/student pattern was typical of reflective tosses in which teacher questions influenced students to clarify their thinking.

A visual representation of this reflective toss is shown in Figure 1. The vertical rectangle represents the teacher question and the two horizontal rectangles represent the student's statements. The longer rectangle on the right represents the student's more elaborated response. We believe that such visual representations can help teachers envision asking questions that elicit elaborations in which students clarify their meanings.

Considering alternative points of view in a neutral manner. Some reflective tosses involve helping students to explore different points of view without privileging one view as correct. For example, during Lesson 2, small groups of students arranged themselves to represent the sun/earth/moon system for a first quarter moon. Students representing the sun and earth stood opposite each other and the student representing the moon stood to one side of the student representing the earth. However, in some groups the "moon" stood to the right of "earth" and in other groups to the left. Wild encouraged the students to consider these differences by asking a reflective toss based upon the students' actions:

	Ss:	[stand to represent the sun/earth/moon system for a first quarter moon]
TOSS	T:	I'd like all groups to sit down except for S10's and S9's groups. Okay, I've seen two different answers and they both make a lot of sense to me. I think we're going to have to choose between one or the other. Here's this "earth," and the "sun" is over here, and the "moon" is on this side. [T points to members of S10's group.] Here's this "earth," and the "sun" is over here, and the "moon" is on this side. [T points to members of S9's group.] Now could the moon be either here or here <no> and (we) have a first quarter moon? <no> Think about that. I'd like you to talk together with your group.
	Ss:	[discuss merits of the different arrangements in small groups]

After acknowledging both positions as sensible, she used a neutral question to encourage students to think about the basis for each view (now could the moon be either here or here and have a first quarter moon?). This question is an example of a reflective toss that "caught" the meaning of diverse student actions and "threw" responsibility for thinking back to the students, to do with each other within their small groups.

After the students had talked about this issue among themselves, Wild moved on to the next step by asking a question that signaled the collaborative nature of the decision they were about to make:

NQ	T:	Who could come up and help us decide? S4?
	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?

	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.
TOSS	T:	Then can you explain why the "earth"...would see the first quarter?
	S4:	Because the sun shines on this side and not on this side.

After she encouraged a student to justify her point of view (why are you choosing this as the correct position?) and the student restated her answer, Wild responded with another request for reasoning (Then can you explain why the earth, why S13 here, would see the first quarter?). These questions are examples of reflective tosses that "throw" responsibility for thinking back to an individual student. In this case, reasoning is elicited in support of a particular point of view rather than clarification of the student's meaning.

Monitoring the discussion and one's own thinking. Some reflective tosses involve helping students to stay engaged in the discussion and to be aware of their own thinking. For example, responding to student questions with "What do you think, from what you know about the moon?" suggests that the students know things and can make useful judgments based upon this knowledge. "Does it make sense that..." implies that the students are actively asking themselves whether they understand what is being proposed. One move common in Minstrell's classroom was also evident in Wild's lessons, taking a poll to see how people are thinking about an issue:

	S17:	Wouldn't it be the right side?
TOSS	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 being neutral about which position was correct, Wild could ask a question that required students to make up their own minds about what they believed (how many think this is the first quarter?). Such responses shift the "authority" for judging right answers from the teacher to the students (Russell, 1983).

Summary. We found that Wild's classroom discourse was similar to Minstrell's in that she asked questions to move forward her agenda (nodal queries) and to explore student thinking (reflective tosses). The latter category included questions that helped students clarify their statements, present reasoning in support of alternative views in a neutral manner, and monitor the discussion and their own thinking.

STUDENT QUESTIONS

Student questions are rare events in classrooms (Biddulph, Symington & Osborne, 1986; Good et al., 1987; Minick, 1991). A typical rate is two informational questions from an entire class each hour (Dillon, 1988b). Wild did not design the lessons analyzed here to promote student questions and not many occurred. However, apparent differences in the nature and frequency of student questions during the two lessons seem to be related to differences in the nature of the questions she asked. We believe there are consistent interactional contexts associated with the presence of student questioning during these lessons. We discuss these below.

Nature and Frequency

Although clear in principle, it is difficult in practice to decide just what constitutes a student question. In identifying student questions, we included more than information-seeking questions (e.g., Does the moon change..going from 3 o'clock to midnight, does it change?). We also included utterances that had the grammatical form of questions asked in the flow of conversation (e.g., Like today, did you see the moon out today?). Although this is an information-seeking question, it might not be counted in a study of student questioning that focused only upon the formulation of substantive issues to be explored. However, we believe that their use is indicative of discourse that differs in interesting and possibly important ways from the recitation structure typically observed in classroom settings. Therefore we chose to include both conversational and informational questions in our analysis of student questioning. A problematic form involved declarative statements that ended with a rising intonation. We omitted these because typically their intent was

to signal that the students were unsure whether their answers were appropriate. In the few cases where a full question form was articulated (Wouldn't it be the right side?) we included the utterance as a question although we would not have included it in an abbreviated form (the right side?). We are limited to considering only those questions that were audible. However, examination of discourse adjacent to inaudible student statements suggests that they did not contain student questions. We discuss below student questions identified in Lessons 1 and 2 and the context within which they were asked.

Lesson 1. During Lesson 1, there was only one audible student question. It followed a teacher question that we would classify as a nodal query (NQ):

NQ T: ...Who could come up and show -
you as the "earth" and this [ball] as the "moon" -
what it looked like when you didn't see the moon
or you [saw] such a little sliver on either side? S18?
S18: So where's the "sun"?
T: Here's the "sun"
as the overhead (projector lamp)...

This seems to have been a low-level information-seeking question prompted by a pragmatic need, to identify the third object representing a member of the sun/earth/moon system. Wild gave an immediate and direct answer.

Lesson 2. During Lesson 2, there were seven audible student questions. Six of these were preceded either by teacher questions that we would classify as reflective tosses (TOSS) or by a teacher statement (TS). One was preceded by a nodal query (NQ) but referred to a preceding teacher statement. These student questions differed both in their apparent intent and in the ways in which Wild responded to them. They were clustered in four episodes:

Lesson 2, Episode A. The first student question in Lesson 2 occurred in the discussion of possible arrangements for the sun/earth/moon system for a first quarter moon. We presented this in the section on reflective tosses but include it here for completeness.

		[Ss and T discuss positions for a "moon" lit on left and lit on the right]
TOSS	T:	...So which is the first quarter, the right side or the left side? S17?
	S17:	Wouldn't it be the right side?
TOSS	T:	...You're not sure, it doesn't sound like, S17. Okay, how many think this is the first quarter?
	Ss:	(some raise hands)

This student question appeared between two teacher questions that we consider reflective tosses, one encouraging students to consider alternative points of view and another asking them to monitor their own thinking. The question requested validation of the student's answer. However, Wild answered this question by reflecting it back to the students rather than by acting as a source of authority for judging right answers.

Lesson 2, Episode B. The second student question during Lesson 2 was substantive but tangential. The question occurred in the midst a discussion of a model for the sun as it appears to move in the sky. Wild's main issue was one of the more difficult conceptual aspects of this lesson, how to think about where the sun is at midnight in this model and how to make connections between this model and one in which the sun is fixed and the earth spins on its axis. Wild broached this issue with a nodal query that she tied in with earlier student thinking:

NQ	T:	Okay, the sun appears to move, somebody said earlier it doesn't actually move
		but it appears to because we're moving,
		it appears to rise and move and set and then we don't see it,
		but what do you suppose happens? S14?
	S14:	The earth is in orbit, it turns around

and then the other side of the world (sees the sun)

She responded to the student's response with a statement rather than a question:

TS T: Depends on where you live. So, you're right.
So you could see the sun from some place on earth all the time
When it's dark here then (it's out at another part of the earth).

Then another student interrupted with a question:

S5: Is that why we have time zones?
Cause it rises in the east and they see it earlier then we do?

The question was related to Wild's topic but she had not planned to discuss time zones in this lesson. She answered briefly and directly by acknowledging that the sun reaches its highest point in the sky at different times in different places and that time zones were set up when people agreed to set all the clocks within a zone to the same time. In under a minute, she had returned to her agenda to use the times (sunrise, noon, sunset, midnight) to talk about where and when one can see the moon. As discussed below, this episode illustrates the dilemmas teachers face if they let students voice questions that come to mind in the midst of a discussion.

Lesson 2, Episode C. The third, fourth, and fifth student questions during Lesson #2 occurred in a long series of exchanges among several students who constructed an explanation with the teacher. These have the grammatical forms of questions that serve conversational functions but they do not articulate informational queries. We have included a lengthy excerpt here as an example of the exploration of student thinking that we believe is important in developing conceptual understanding. In this case, Wild tried to understand an unanticipated student comment that other students supported. When exploration did not result in changing the students' views, she decided to move on and did so without judging the view's validity from her perspective. This episode is an example of taking time to explore an unanticipated student idea and then choosing to withhold judgment and postpone resolution in order to return to the main agenda. The episode also provides an example of the complex interplay typical in a series of reflective tosses that engage individual students and their peers in a conversation with their teacher.

Wild launched the episode with a poll that served as a nodal query for the next step:

NQ T: You told me yesterday, you can see the moon at different times. You've seen it at night and you've seen it in the day time. ...How many would say the moon is always visible to us? ...And who would say no, the moon is not always visible to us?

After students responded that the moon is not always visible, she asked for an explanation:

Ss: [lots of students raise their hands]

TOSS T: ...Does anybody have a reason for why it's not always visible to us? Why do you think, S3?

After an expected answer, that one might be on the wrong side of the earth, she called on another student:

S25: Well, sometimes the sunlight is too bright, and it kind of blocks out what is reflecting off the moon, so it's just almost like the moon isn't there.

TOSS T: What phases of the moon would that be, S25, that you are referring to?

She was asking for explicit identification of the phases she intended to discuss, the very slim waning and waxing crescents that one sees just before sunrise or just after sunset, just before or after new moon. In these situations, the moon seems to be "not there" during the day but actually is only "not visible." However, the student was thinking about a different situation. Wild explored this by asking for clarification and for comparison with a related situation:

	S25:	Usually a half moon or a crescent
TOSS	T:	Okay, I'm not sure I, I guess what I'm thinking is are you looking at the sun so its hard to look?
	S25	Well no the sun just sort of, it gives so much light to the moon, but then the power of the sun is sometimes too bright so that, rays to bounce off for us to see it.
TOSS	T:	So are you saying that sometimes the moon doesn't reflect the sun's rays?
	S25:	Well it reflects it, but the sun's rays that aren't reflected off the moon are too bright for us to see because the rays aren't strong enough.
TOSS	T:	Do you compare that in any way to seeing or not seeing stars in the night time or day time, S25?
	S25:	Not really.
TS	T:	Think about that some and I'd love to talk to you more about that.

After validating the interaction, she called on another student, who used her suggestion about a related situation to speak in support of S25:

	S19:	Well, there's sometimes there's clouds, and also just like stars, during the day time you can't see stars because it's not dark and you see the sun, but you can't see the stars out, and the same thing happens with the moon even though the moon doesn't produce its own light.
TS	T:	So you're thinking the same as S25.

Here Wild made a statement that served the same function as a reflective toss that helped students monitor the discussion and their own thinking. Another student offered an analogous situation in support of S25 and S19:

S11: Like S19 said, we don't see...the stars in the daytime because

it's light out,
it, wouldn't that be like in the middle of the daytime
it would be like trying to see something with a flashlight,
you wouldn't be able to see it,
but at night you can see the rays coming out because it's darker out.

Then Wild asked three of the students to act out the situation they were envisioning. Several used questioning forms as they worked together to explain what they meant:

TOSS	T:	Well S14, S19, and S25, why don't you stand up, ...let's say it's daytime and there aren't any clouds. S25, you be the "sun", and S14, you be the "earth". And then, can you move S19 to where you think you wouldn't see him?
	S25:	...<u>where the "earth" wouldn't see the "moon", during the daytime</u>?
TOSS	T:	...Can you use this to explain to me what you're saying?
	S19:	We're saying that sometimes you can't see the sun out or the moon out. <u>Like today, did you see the moon out today</u>?
TS	T:	I haven't seen it yet
	S19:	<u>You haven't seen it</u>? Well because, like you can't see the stars out during the daytime because, it's tough to explain, it's too bright and the
TS	T:	I understand the star part. I understand how the sun's out now so we get light from the sun, we get light from the stars, but we don't see them in bright sunlight. But I am not sure what position the moon would be in when we wouldn't see it.
	S19:	<u>What position would the moon be</u>? Well,

		if we didn't see it, then how would we know what position it would be in?
TS	T:	Well, S25 was saying there were times when you wouldn't see it.
	S25:	Well, it could pretty much just be in any position.
TOSS	T:	So you think, like we decided this was the first-quarter moon, So now you think there's a time when we wouldn't see the first-quarter moon?
	S25:	If the sun was too bright.
...		
TS	T:	Okay, I understand what you're saying. Okay. Thanks for showing me that.

S25 checked his understanding of the task ([to move the student representing the moon to] where the "earth" wouldn't see the "moon" during the day?). S19 engaged the teacher's experiences (did you see the moon out today?) and questioned her question (if..., then how would we know....). Wild did not evaluate the students' claim nor refute it at this point but called upon another student. After he described the "new moon" situation that she had anticipated discussing, Wild decided to move on to discuss her next topic, ways in which the moon appears to move across the sky. She waited until a later lesson to reconsider the situation S14, S19, and S25 had proposed.

Lesson 2, Episode D. The sixth and seventh student questions during Lesson 2 voiced a substantive new idea. This episode is an example of acknowledging an unanticipated student question and then sharpening it for further consideration by the entire class. The student question apparently was triggered by the teacher statement preceding a nodal query and invoked a deep philosophical issue, whether change is continuous or discontinuous.

TS	T:	...now we know we can go out at 9 o-clock and midnight [to see a full moon]
NQ		And any other times? S3?
	S3:	Does the moon change..going from 3 o'clock to midnight does it change?
	...	
TOSS	T:	If it's a full moon does it change?
	S3:	Yeah, no, if it's a crescent.
TOSS	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.
TOSS	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?

Wild stated the current understanding about when to look for a full moon (...go out at 9 and midnight) and then returned to the node for this segment of the discussion (and any other times?). The student interrupted with a question relevant to the situation but not to the immediate topic. Wild responded by clarifying (if it's a full moon, does it change?) and encouraging the student to monitor his own thinking (what do you think...). Then the student asserted a position. After Wild asked him to evaluate an elaborated version of his position (Does it make sense...), the student narrowed the time period of his query. Wild responded by the elaborating his question further, " 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?" Then she and the students went on to discuss this issue further.

RELATION OF TEACHER AND STUDENT QUESTIONING

The students asked one audible question during Lesson 1 and seven during Lesson 2. The only student question identified in the transcript of Lesson 1 was a low-level information-seeking question prompted by a

pragmatic need. Students asked questions during Lesson 2 in the process of verifying a belief, raising a tangential but substantive issue, engaging the teacher in constructing an explanation, and voicing a substantive new idea.

We believe that the differences in the nature and frequency of student questions during Lessons 1 and 2 are related to differences in the teacher's intentions in conducting the lessons and in turn to differences in the nature of some of her questions during these lessons. In Lesson 1, Wild's intention was to lead the students through a process of model building step by step. She wanted to keep the students thinking together along a particular sequence of reasoning and did so by asking primarily nodal queries, questions that prompted the next step. In Lesson 2, Wild was willing to explore student ways of thinking and did so by asking reflective tosses, questions that elicited additional student comments and questions. During Lesson 2, the presence of student questions was associated with teacher questions that encouraged students to make their meanings clear, consider alternative points of view in a neutral manner, and monitor the discussion and their own thinking, that is, with reflective tosses that followed the students' lead in thinking. Such teacher questions seemed to loosen the structure of the lesson in ways that enabled students to gain sufficient entry into the dialogue to engage in conversations and to voice their own concerns. The teacher statement that preceded the student question in Episode B supports the suggestion that student questions are associated with interactional contexts in which teachers do not ask questions (Costa, 1985; Dillon, 1978).

The relationship suggested by these data needs further exploration. In particular, we plan to examine teacher and student questioning during other lessons when Wild does not feel constrained to "get through" particular subject matter topics in such a limited time period. We are particularly interested in analyzing more examples of student questioning similar to those in Episodes C and D. We expect reflective tosses to be prevalent when several students in the class participate vigorously in constructing explanations and exploring a substantive and relevant issue raised by a student question. We expect nodal queries to be prevalent in lessons in which student participation is limited and student questions rarely appear.

DECISION DILEMMAS DURING CLASS DISCUSSIONS

Wild's intention in Lessons 1 and 2 was to demonstrate for Flanagan a way of teaching in which questioning is used to elicit observations from students, to build a conceptual framework that makes sense of the observations, and then to apply the framework productively in making predictions. In this case, she planned to review the students' observations of the moon, to guide them in building a model for the relative positions of the sun, earth, and moon that cause us to see different phases of the moon, and then to use that framework in making predictions of when and where to look for particular phases. Because these were demonstration lessons conducted within a limited time period, she wanted to complete the main conceptual moves and did not intend to elicit student questions. As she commented during the research conversations, "the point of these lessons in my mind was not to specifically elicit students' questions as to get them to think in a certain way."

During Lesson 2, however, Wild loosened the structure of the dialogue in ways that allowed students to ask some questions. In the preceding sections, we have described this loosening as a shift from asking nodal queries that take the next step in the teacher's agenda to using reflective tosses that explore student thinking. The result of this loosening of the dialogue was a shift from "marching through" the main ideas of the lesson to "making excursions" through closely related topics prompted by student comments and questions. The effect of this shift on Flanagan was a decision not to attempt Lesson 2. She felt "it wasn't structured enough, I wasn't confident that I would know what structure to follow."

During our research conversations, we discussed the differences in these two lessons and identified dilemmas that we as teachers face in conducting discussions both with children and adult students. These included whether to take time to explore student thinking, how to respond to "wrong" answers, what types of questions to ask, and how to encourage all students to participate. We discuss these below and indicate issues that need further investigation.

Dilemma #1: Whether to take time to explore student thinking

As teachers, we agreed that there are rhythms in lessons, "opening up" conversations when we might explore student thinking in detail and "closing down" sessions when we probably would not. We also agreed that a difficult aspect in conducting discussions is balancing our plans with our students' interests. Flanagan expressed this dilemma as follows: "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?" In Episode B, for example, Wild gave a brief direct response to a student question about time zones but in Episode D she elaborated a student question about changes in the moon's phases and engaged other students in discussing it. Both student questions were unanticipated, both interrupted her intended next step. To one, however, she gave a direct answer in under a minute; to the other she devoted considerable resources in time and class attention. One she regarded as tangential, the other as relevant, but both presented a dilemma that Wild described as follows:

> I think that students' questions, like the time zone and so forth, I would always want to answer each one. The dilemma is, if I do, what's going to happen to the rest of the class? So when Sue put her head down on her desk, when I saw one student obviously not interested...the dilemma is how interested is everyone else in this and how turned off to the lesson are the other members of the class going to get?

In addition to losing interest, some members of the class may get confused if there are too many digressions. Flanagan, for example, noted that she may lose a student who is understanding the lesson if she tries to answer another student's question:

> How can the teacher make a decision about which student is more important? You know, is it more important that this student understand that question? Or is it more important to keep this student with me? That's a tough question.

However, these teachers also placed a high value on student questions. For example, Flanagan commented that, "As a teacher, I feel students'

questions to me are more important than my questions to them because that shows me that they're trying to understand something."

For Wild, "the dilemma lies in deciding how to respond to student questions." There are large differences in the time required to set a student question aside, answer directly, or try to work with the students' ideas through an extended discussion. We identified several factors that influence this decision: the intent of the lesson, how closely related the question is with the objective of the lesson, whether it might be answered best with factual information or through questioning, how much the rest of the class seems interested, how knowledgeable one is 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. Further research is needed to document such decisions in more detail and to try to specify criteria that teachers use in making them.

Dilemma #2: How to respond to a "wrong" answer

A second dilemma we face as teachers involves ways of responding to "wrong" answers. Should we correct a student immediately, for example, or engage the student in some exploratory thinking? During the discussion of rising and setting times, for example, a student claimed that a full moon might be seen at noon. Rather than rejecting this answer outright, Wild asked the student to demonstrate an arrangement for the sun at noon, the earth, and a full moon. By working out the model for this situation, the student was able to conclude that a full moon would not be visible at noon. Wild summarized her philosophy as follows:

> If the students are bringing up something that there's an answer for, if it's an answer they can discover for themselves, I'd like to encourage them to find the answer and hopefully ask questions or give information or suggestions that would help them find information. If...there's a misconception...then I would hope to...not let them continue with the misconception...Now if conceptually they believe this, the chances are unless I take them through the experience they're still going to believe it anyway; I mean just saying it to them, they're not going to go away and think any differently if they're not questioning it in their own mind. So I feel I have to have them question it in their own mind.

Wild often acknowledged "wrong" answers as reasonable ways to be thinking (e.g., I've seen two different answers and they both make a lot of sense to me. I think we're going to have to choose between one and the other..."). Then she engaged students in figuring out which way seemed better after careful examination of the evidence. Some wrong answers were anticipated parts of the action, such as whether the "moon" should stand to the left or right of the "earth" to represent the sun/earth/moon system for a first quarter moon. Others emerged unexpectedly in the midst of a conversation, such as the discussion in Episode C about whether a first quarter moon would be visible if the sun were shining too brightly. Episode C illustrates some of the difficulties in this approach to teaching. Wild experienced a feeling of confusion in trying to understand what these students were saying. Taking time to work through the model with them did not seem to change their views, although doing this had helped the student who thought a full moon would be visible at noon. Such explorations also have costs in time and student attention. As Flanagan commented, "if you explore where that (idea) came from, and go into the topic then you're going to really be changing your plan for your lesson." Further research is needed to document how teachers respond to wrong answers as they make tough moment-by-moment decisions to allocate time and topic during a discussion.

Dilemma #3: What type of questions to ask

Wild intended the lessons as a guided experience in the sophisticated kind of thinking called model building. However, in leading the students through the process of constructing a conceptual model for the moon's phases in Lesson 1, she asked many "low level" factual questions (Bloom, 1956). She believed that these served her purposes well and were she to do Lesson 1 again she would do it in the same way. In exploring student thinking in Lesson 2, Wild used many reflective tosses, which could be classified as a variety of "higher level" questions (Bloom, 1956). However, Wild and Flanagan both felt less comfortable with Lesson 2 than with Lesson 1. Flanagan, for example, was unsure of its point and chose not to try to replicate it with her own class. Although reflective tosses were associated with greater student talk and with more student questions, it is not clear whether they were associated with greater learning. Nor is it clear how to

define and assess learning that might have occurred during the conceptual thinking and spatial orienting in which Wild engaged the students during Lesson 2. Although we believe that the students who participated in Episode C learned something of value through the process of constructing an explanation, it is not clear to what extent their classmates learned anything by observing it. In laboratory studies, for example, preliminary data suggest that people do worse on an inferential problem solving task if they hear an explanation than if they hear a summary of a text (Coleman, 1992). Further research is needed to clarify what students learn in the context of different kinds of classroom conversations.

Dilemma #4: How to encourage all students to participate

Both Wild and Flanagan called upon more than twenty different students during their lessons. They intentionally tried to be aware of whom had spoken already and to bring all the students into the conversation, particularly the girls. Flanagan explained her policy as follows:

> I make an effort to call on the students who don't have their hands up. And they may not like it, because they may not always know what to say. But I, if I didn't,...S23 and S19 (and I)...would just have class all day together and most everybody else would sit back. And it's very frustrating as a teacher to have to try and deal with this but it is something that has been with these kids since very long ago...they may feel their opinions and their thoughts are not as important or as valid as the other students.

Difficulties that girls experience in talking in science classes have been explored in a number of contexts (Hacker, 1991). One factor that seems to facilitate entry for girls is the presence in the class of at least one girl who participates regularly (Corey et al., 1993). Further research is needed to identify and develop ways of speaking that enable all class members to participate.

SUMMARY

We believe that programs for teachers need to address explicitly ways to conduct the interactive dialogues currently being promoted in reform movements in mathematics and science education. In this study, we have

developed several documents intended for use in such programs. The narrative analyses demonstrate an instructional approach in which the teacher guides the building of a conceptual model through questioning. The transcript excerpts of Episodes A-D illustrate interactional contexts associated with student questioning. If examined in small group activities and group discussions, these documents provide examples for considering ways in which teachers can use questioning to guide student thinking.[1]

In our analysis of teacher questions, we have used a new language for talking about questioning. Rather than focusing upon the cognitive level of a question, we emphasize two central functions of teacher questions that often are in tension during class discussions: moving a teacher's agenda forward and exploring student thinking. We have used a questioning framework based upon a teacher's metaphors for discussions: networks and negotiations. "Nodal queries" are teacher questions that move the discussion through a "network" of planned topics. "Reflective tosses" are teacher questions that facilitate the expression of student thinking. The categories for "reflective tosses" highlight three important processes in negotiations: making meanings clear, exploring alternative points of view in a neutral manner, and monitoring a discussion and one's own thinking. Although this framework was developed in the context of a high school physics classroom, we found that it was descriptive of questions asked in conversations about the phases of the moon with younger students.

The representation in Figure 1 is intended to help teachers visualize a major goal of teacher questioning: enabling students to elaborate their thinking. One outcome of such teacher questioning seems to be an increase in student questioning. However, encouraging and responding to student questions can increase the dilemmas teachers experience in conducting discussions. Such dilemmas include whether to explore a student's thinking, how to respond to "wrong" answers, what type of questions to ask, and how to encourage all students to participate. Further research is needed to identify how teachers resolve such dilemmas in ways that facilitate learning. We believe that explicitly recognizing such dilemmas is important in enabling teachers to risk undertaking an interactive approach to teaching and learning.

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ENDNOTE

1. Copies of the narrative analyses and Episodes A-D are available from the first author.

REFERENCES

Alpert, B.R. (1987). Active, silent, and controlled discussions: Explaining variations in classroom conversation. *Teaching & Teacher Education 3(1)*, 29-40.

Arons, A. (1972). Anatomy of an introductory course in physical science. *Journal of College Science Teaching 1*(4), 30.

Bellack, A.A., Kliebard, H., Hyman, R., & Smith, F. (1966). *The Language of the Classroom*. New York: Teachers College Press.

Biddulph, F., Symington, D. & Osborne, R. (1986). The place of children's questions in primary science education. *Research in Science & Technological Education 4(1)*, 77-88.

Bloom, B.S. (Ed.). (1956). *Taxonomy of educational objectives: Handbook I, The cognitive domain*. New York, NY: David McKay.

Brown, A.L. & Palinscar, A.S. (1987). Reciprocal teaching of comprehension strategies: A natural history of one program for enhancing learning. In J.D. Day & J. Borkowski (Eds.), *Intelligence and exceptionality: New directions for theory, assessment and instructional practice* (pp. 81-132). Norwood, NJ: Ablex.

Carlsen, W.S. (1991). Questioning in classrooms: A sociolinguistic perspective. *Review of Educational Research 61(2)*, 157-178.

Cazden, C.B. (1970). Children's questions: Their forms, functions and roles in education. *Young Children 25*, 202-220.

Cazden, C.B. (1986). Classroom discourse. In M. Wittrock (Ed.), *Handbook of Research on Teaching (3rd ed.)*. New York: Macmillan.

Cazden, C.B. (1988). *Classroom discourse*. Portsmouth, N.H.: Heinemann.

Chastain, P.L., Oberem, G.E., & McDermott, L.C. (1993, August). Investigating common conceptual and reasoning difficulties in introductory astronomy. Paper presented at the summer meeting of the American Association of Physics Teachers, Boise.

Cicourel, A.V., Jennings, K.H., Jennings, S.H.H., Leiter, K.C.W., Mackay, R., Mehan, H., & Roth, D.R. (1974). *Language use and school performance*. New York: Academic Press.

Cobb, P., Wood, T., & Yackel, E. (in press). Discourse, mathematical thinking, and classroom practice. In N. Minick, E. Forman, & A.

Stone (Eds.). *Education and mind: Instructional, social, and developmental processes*. Oxford: Oxford University Press.

Coleman, E. (1992). Articulation of explanation as a mechanism for retrieval, comprehension and inference: A situation-based model. Proposal for the James S. McDonnell Foundation.

Collins, A. & Stevens, A.L. (1982). Goals and strategies of inquiry teachers. In R. Glazer (Ed.), *Advances in instructional psychology Vol 2* (pp. 65-119). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Corey, V., van Zee, E.H., Minstrell, J., Simpson, D., & Stimpson, V. (1993, April). When girls talk; An examination of high school physics classes. Paper presented at the annual

meeting of the National Association for Research in Science Teaching, Atlanta.

Costa, A.L. (1985). Teacher behaviors that enable student thinking. In A.L. Costa (Ed.), *Developing Minds: A resource book for teaching thinking (pp. 125-137)*. Association for Supervision and Curriculum Development.

Cox, D.C. (1989). *Focus on science concepts. Science concept working papers*. Salem, OR: Oregon State Department of Education.

Cox, D.C. (1990). *A discussion of concept/process-based science*. Salem, OR: Oregon State Department of Education.

diSessa, A., Hammer, D., Viis, B., & Vise, L. (1991). Inventing graphing: Meta-representational expertise in children. *Journal of Mathematical Behavior 10*, 117-160.

Dillon, J.T. (1978). Using questions to depress student thought. *School Review 87*, 50-63.

Dillon, J.T. (1985). Using questions to foil discussion. *Teaching & Teacher Education 1*, 109-121.

Dillon, J.T. (Ed.). (1988a). *Questioning and discussion.* Norwood, NJ: Ablex Pub.

Dillon, J.T. (1988b). *Questioning and teaching*. New York, NY: Teachers College Press.

Dillon, J.T. (1988c). The remedial status of student questioning. *Journal of Curriculum Studies 20 (3)*, 197-210.

Driver, R., Guesne, E. & Tiberghien, A. (Eds.) (1985). *Children's ideas in science*. Philadelphia, PA: Milton Keynes, Open University Press.

Edwards, A.D., & Furlong, V.J. (1978). *The language of teaching: Meaning in classroom interaction*. London: Heinemann.

Elementary Science Study (1971). *Where is the Moon?* New York: McGraw-Hill.

Erickson, F. (1986). Qualitative research on teaching. In M.C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed.). New York: Macmillan.

Foster, G.W. (1993). Third and fifth grade student ideas for the moon's phases before and after an earth point of view activity. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta.

Gall, M. (1984). Synthesis of research on teachers' questioning. *Educational Leadership 42*, 40-47.

Good, T.L., Slavings, R.L., Harel, K.H., & Emerson, H. (1987). Student passivity: A study of question asking in K-12 classrooms. *Sociology of Education 60*, 181-199.

Graesser. A.C. (1990). Psychological research on question answering and question asking. *Discourse Processes 13 (3)*, 259-260.

Hacker, R.G. (1991). Gender differences in science-lesson behaviours. *International Journal of Science Education 13(4)*, 439-4446.

Hall, R. (1990). Making mathematics on paper: Constructing representations of stories about related linear functions. IRL Monograph No. IRL90-0002, Institute for Research on Learning, Palo Alto, CA.

Hunkins, F. (1976). *Involving students in questioning*. Boston, MA: Allyn & Bacon.

Hunkins, F. (1989). *Teaching thinking through effective questioning*. Boston, MA: Christopher-Gordon.

Hymes, D. (1962). The ethnography of speaking. In T. Gladwin and W.C. Sturtevant (Eds.), *Anthropology and human behavior* (pp. 13-53). Washington, D.C.

Hymes, D. (1972). Models for the interaction of language and social life. In J.J. Gumperz & D. Hymes (Eds.), *Directions in sociolinguistics: Ethnography of communication* (pp. 35-71). New York: Holt, Rinehart and Winston.

Hymes, D. (1982). What is ethnography? In P. Gilmore and A. Glatthorn (Eds.), *Children In and out of school: Ethnography and education*. Washington, D.C.: Center for Applied Linguistics.

Jacob, E. (1987). Qualitative research traditions: A review. *Review of Educational Research 57(1)*, 1-50.

Karplus, R. (1964). Science Curriculum Improvement Study. *Journal of Research in Science Teaching 2*, 293-303.

Klein, C.A. (1982). Children's concepts of the Earth and the Sun: A cross cultural study. *Science Education 65*(1), 95-

Lowery, L. (1980). Learning about instruction: Teacher-initiated statements and questions. Berkeley, CA: University of California Professional Development and Applied Research Center.

Lemke, J.L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex.

Lichtman, A. & Sadler, P. (1993). Teacher predictions versus actual student gains. *The Physics Teacher 31*, 162-167.

McDermott, L.C. (1990). A perspective on teacher preparation in physics and other sciences: The need for special science courses for teachers. *American Journal of Physics 58(8)*, 734-742.

McDermott, L.C. (in press). *Physics as Inquiry*. Modules are currently available through the Physics Education Group, Department of Physics, University of Washington.

Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA: Harvard University Press.

Minick, N. (1991, April). Learning to ask questions in primary school science lessons: An introduction to scientific thought and discourse? Paper presented at the American Educational Research Association annual meeting, Chicago.

Minstrell, J. (1978). *An evaluation of the University of Washington program in physical science and science teaching for elementary school teachers*. Unpublished dissertation. University of Washington, Seattle.

Minstrell, J. (1989). Teaching science for understanding. In L.B. Resnick and L.E. Klopfer (Eds.), *Toward the thinking curriculum: Current cognitive research*. 1989 Yearbook of the Association for Supervision and Curriculum Development.

Moschkovich, J.M., Schoenfeld, A. & Arcavia, A. (1993). Aspects of understanding: On multiple perspectives and representations of linear relations and connections among them. In T.A. Romberg, E. Fenema, and T.P. Carpenter (Eds.), *Integrating reserach on the graphical representation of function*. Hillsdale, NJ: Erlbaum.

Nussbaum, J. (1979). Children's conceptions of the earth as a cosmic body: A cross age study. *Science Education 63*(1), 83-93.

Palinscar, A.S. & Brown, A.L. (1984). Reciprocal teaching of comprehension fostering and monitoring activities. *Cognition and Instruction 1*, 117-175.

Pea, R. (1991). Augmenting the discourse of learning with computer-based learning environments. In E. de Corte, M. Linn, H. Mandl & L. Verschaffel (Eds.), *Computer-based learning environments and problem-solving*. (NATO Series ASI Series F). New York: Springer-Verlag.

Philipsen, G. (1977). Linearity of research design in ethnographic studies of speaking. *Communication Quarterly 25*, 42-50.

Philipsen, G. (1982). The qualitative case study as a strategy in communication inquiry. *The Communicator 12*, 4-17.

Philipsen, G. (1992). *Speaking culturally: Explorations in social communication*. New York: SUNY Albany Press.

Redfield, D.L. & Rousseau, E.W. (1981). A meta-analysis of experimental research on teacher questioning behavior. *Review of Educational Research 51(2)*, 237-245.

Rowe, M.B. (1986). Wait time: Slowing down may be a way of speeding up! *Journal of Teacher Education*, 43-50.

Russell, T.L. (1983). Analyzing arguments in science classroom discourse: Can teachers' questions distort scientific authority? *Journal of Research in Science Teaching 20*, 27-45.

Saha, P.K. (1984). Bengali. In W.S. Chisholm, L.T. Milic, & J.A.C. Greppin (Eds.), *Interrogativity: A colloquium on the grammar, typology, and pragmatics of questions in seven diverse languages*. Philadelphia, PA: John Benjamins.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *The Journal of the Learning Sciences 1(1)*, 37-68.

Schatz, D. (1991). *Astronomy activity book*. New York: Simon & Schuster.

Schnepps, M. (1986). *A private universe*. Pyramid Films.

Sigel, I.E. & Saunders, R. (1979). An inquiry into inquiry: Question-asking as an instructional model. In L. Latz (Ed.), *Current Topics in Early Childhood Education*. Norwood, N.J.: Ablex.

Sinclair, J. McH. & Coulthard, M. (1975). *Towards an analysis of discourse: The English used by teachers and pupils*. London: Oxford University Press.

Suchman, J.R. (1961). Inquiry training: Building skills for autonomous discovery. *Merrill Palmer Quarterly 7*, 147-169.

Tharp, R.G. & Gallimore, R. (1988). *Rousing minds to life: Teaching, learning, and schooling in social context*. Cambridge: Cambridge University Press.

Tobin, K. (1987). The role of wait time in higher cognitive level learning. *Review of Educational Research 57(1)*, 69-95.

van der Meij, H. (1986). *Questioning*. The Hague: Stichting voor Onderzook.

van Zee, E.H. (1992). Investigation of Questioning Processes during Conversations about Science. Proposal to the National Science Foundation.

van Zee, E.H. (1990). Investigation of Questioning Processes in a Cognitive Approach to Physics Instruction. Postdoctoral fellowship awarded by James S. McDonnell Foundation Program in Cognitive Studies for Educational Practice.

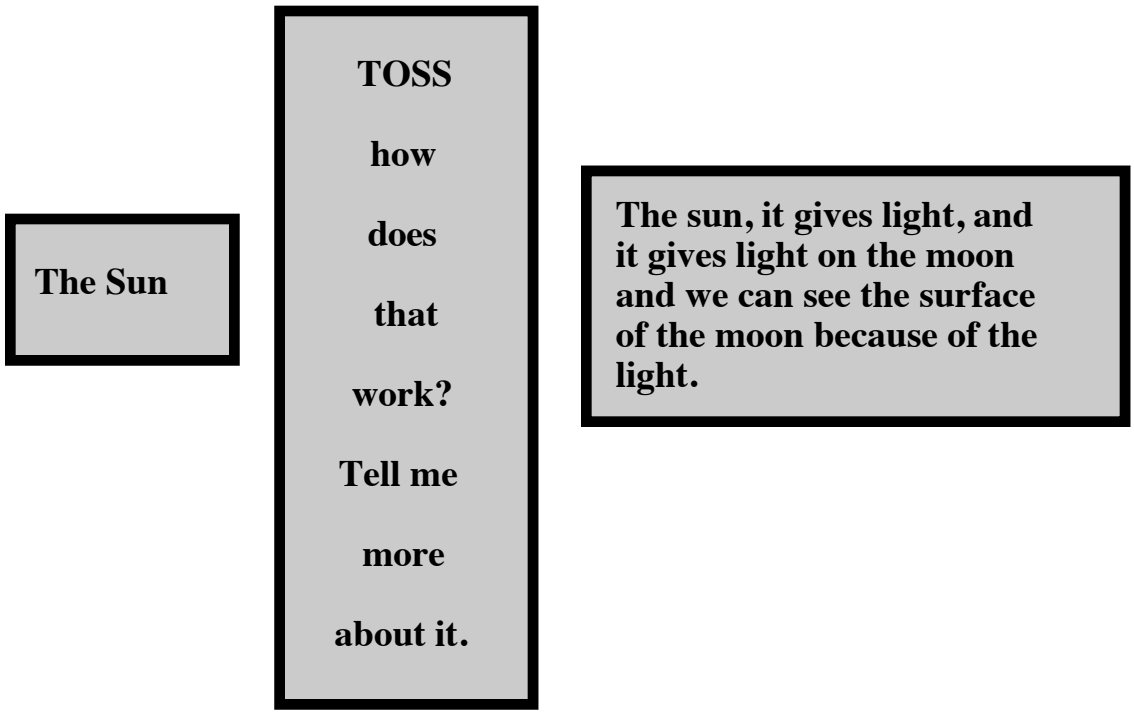
van Zee, E.H. & Minstrell, J. (1991a). Reflective discourse: Negotiating shared meaning in a physics classroom. Report to the James S. McDonnell Foundation.

van Zee, E.H. & Minstrell, J. (1991b). Using questioning to guide student thinking. Paper presented at American Educational Research Association meeting, Chicago.

van Zee, E.H., Minstrell, J., Simpson, D., & Stimpson, V. (1992, April). Reflective discourse: Talking together about physics. Paper presented at the American Educational Research Association 1992 annual meeting, San Francisco

Wild, J. (1989). *Science in the elementary school: A guide for teachers*. Text for science methods course, Seattle University.

Wilen, W.W. & Clegg, A.A. (1986). Effective questions and questioning: A research review. *Theory and Research in Social Education 14(2)*, 153-161.



A reflective toss "catches" the meaning of the prior student utterance and "throws" responsibility for thinking back to the student.

Figure 1: Visual representation of a reflective toss. The teacher asked a question that helped a student make his meaning clear. The vertical rectangle represents the teacher question. The horizontal rectangles represent the student statements. The student/teacher/student pattern shows ways in which the teacher influenced student thinking by asking for an elaboration of the prior student utterance.

Example reflective tosses that helped students:

Make their meanings clear:

Episode C:
So are you saying that sometimes the moon doesn't reflect the sun's rays?

Well S14, S19, and S25, why don't you stand up...let's say it's daytime, and there aren't any clouds, S25, you be the "sun" and S14 you be the "earth" and then, can you move S19 to where you think you wouldn't see him?
Can you use this to explain to me what you're saying?

Episode D:
(paraphrases of the student's question)
If it's a full moon, does it change?
If it's a crescent, does it change?

Consider alternative points of view in a neutral manner:

Episode A:
Who has an answer and a reason for your answer?

Now we're going to have S12 come up and the question is S12 should you be over there, or should you be over here?

What we want to know is why are you choosing this as the correct position?

2Can someone come up and, following what S15 was saying, try to help us figure out what S12's going to look like here as the "moon" when she changes to that position?

And what, as you're looking from the "earth," what side would that be? Would that be the right side or the left?

Episode D:
Is it always going to be dark when I see the full moon?
Could I go out at noon and see it?

Can you describe how I would go out at noon, why I could go out at noon and see a full moon?
Why?
Where would the sun be at noontime? Okay, now where would the moon have to be if it's full?

So you think it's different each day when you see it, can you describe how you think that happens?

Monitor the discussion and their own thinking:

Episode A:
You're not sure, it doesn't sound like, Okay, How many think this is the first quarter?

Episode D:
What do you think, from what you know about the moon?

Do you think, does it make sense that it's a crescent for a whole day and then it changes to a different crescent for a whole day and then changes to another?

Do you want someone in your group to help you with that?

Figure 2: Teacher questions associated with student questions during Lesson 2