Using Questioning to Facilitate Discussion of Science Teaching Problems in Teacher Professional Development

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Abstract

Previous research has shown that questioning is a key strategy that facilitators use to promote discussion in Problem-Based Learning (PBL). Yet, there is a lack of detailed understanding on what questions facilitators ask and how those questions affect discussion. In this study we examined different types of questions that experienced facilitators asked to promote discussion of teaching problems in professional development for science teachers. We videotaped six PBL sessions facilitated by three pairs of experienced facilitators. Data analysis showed that facilitators asked a set of questions to initiate and advance PBL discourse, including questions to solicit ideas, to reframe ideas, to clarify ideas, to push for elaboration, to check for interpretation, and to connect to teachers' classroom practice. This study has implications for the development of PBL facilitators.

A sociocultural view of learning places great emphasis on the role of language and discussion in the process of knowledge construction (Dillon, 1994; Lemke, 1990). Discussion is a key feature of Problem-Based Learning (PBL) (Barrows, 1988; 1996). In PBL group discussion, collaborative knowledge construction is achieved through activating learners' prior knowledge, identifying knowledge deficits, questioning each other, reasoning with evidence, and reconciling multiple perspectives (Dolmans & Schmidt, 2006; Hmelo-Silver, 2004). However, such discussion rarely occurs spontaneously. Problems and cases, however well designed, do not teach themselves (Shulman, 1996). Facilitators play an essential role in structuring and guiding PBL discussion (Dolmans et al., 2002; Savery,

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2006). The important role of facilitation has been documented in a few detailed analyses of PBL tutorial processes (Glenn, Koschmann, & Conlee, 1999; Hmelo-Silver & Barrows, 2006; 2008; Palincsar, 1999).

Our previous research has shown that experienced facilitators used a variety of strategies during PBL group discussions (Zhang, Lundeberg, McConnell, Koehler, & Eberhardt, 2009). Particularly, we found questioning was the strategy most frequently used by all facilitators in all PBL sessions. Just as "Teacher questions are frequent, pervasive, and universal phenomena" (Roth, 1996, p. 710), facilitators often use questioning to engage participants in discussion. Given the prominence of questioning, in this study we aimed to understand how experienced facilitators used questioning to guide PBL group discussions.

Research on questioning has mainly occurred in K-12 classroom settings focusing on the *types* of questions asked by teachers (e.g., Chin, 2007; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001), with only a few studies that examined questions asked by PBL facilitators in medical education (e.g., Hmelo-Silver & Barrows, 2008). Student-centered, inquiry-based classroom teaching shares important principles with PBL because both emphasize that learning is actively constructed by learners and students should take responsibility for their learning. Therefore, understanding of effective teacher questioning has important implications for PBL facilitation. In the following section, we briefly review the findings on teacher questioning in classroom instruction, and then turn to studies on questioning in PBL facilitation.

Using questioning to guide student thinking in classrooms

Teacher questioning is a key component of classroom discourse. According to Graesser and Person (1994), teachers asked roughly 30-120 questions per hour, depending on the activity types (e.g., whole-group discussion or routine seat work). Questions are not universally effective, however. Early research identified a typical classroom discourse pattern that contains a three-part exchange: Initiation-Response-Evaluation (IRE) (Cazden, 1986; Mehan, 1979). That is, a teacher initiates a question that typically aims to ask students to recite what has been taught, and then a student responds to the question, which is followed by an evaluation from the teacher. As prevalent as the IRE pattern is in classroom discourse, it is generally considered ineffective in leading to meaningful discussion, thus providing limited learning opportunities (Lemke, 1990).

Later, a number of studies explored the characteristics of teacher questioning that had potential to foster productive discussion (Nystrand, Wu, Gamoran, Zeiser, & Long, 2003; van Zee et al., 2001; van Zee & Minstrell, 1997; Wells & Arauz, 2006). First, van Zee and Minstrell (1997) described a particular kind of questioning, used by an experienced high school physics teacher to stimulate student thinking, that they called *reflective toss*, in which the teacher tried to "catch" the meaning of a student's idea in the previous turns and "throw" a question back to students to elicit further thinking. Unlike IRE, a reflective toss consists of a different three-part exchange: a student statement, teacher question, and additional student statements.

In another study of her own teaching in undergraduate courses and four other K-12 science teachers' practice, van Zee et al. (2001) reported that during science discussion, teachers asked questions to elicit student ideas, to diagnose and refine those ideas, to clarify meaning, to consider multiple perspectives, and to monitor discussion and student thinking.

Other studies explored the conditions under which questioning might lead to productive discussion, or dialogic discourse. Researchers who studied classroom questioning typically operationalized dialogic discourse by the number of participants involved and the duration of sustained discussion. For example, Nystrand et al. (2003) defined productive discussion as "free exchange of information among at least three students and the teacher that lasted at least a half-minute during a classroom instructional episode" (p. 174).

Drawing upon 872 class observations in 112 eighth- and ninth-grade English and social studies classes in 16 schools, Nystrand et al. (2003) identified three important conditions that were likely to lead to dialogic discourse: 1) authentic questions asked by teachers that did not have a predetermined answer, 2) uptake of students' ideas (i.e., a teacher's question incorporated students' contributions in previous utterances), and 3) student questions. This study suggested the importance of teachers asking authentic questions and building on student ideas.

Another longitudinal study on classroom discourse in elementary and middle school science classes revealed similar insights (Wells & Arauz, 2006). Wells and Arauz studied whole-class discussions from nine teachers' classrooms who participated in a project that spanned seven years. They distinguished two types of teacher questioning: Known information questions that aimed at getting students to display what was supposed to be known, and negotiatory questions that led to open-ended discussion. They found that over an extended period of time of adopting an inquiry-based approach to teaching, teachers were more likely to ask negotiatory questions than known information questions, and their follow-up moves after initial questions were more likely to show uptake of students' ideas. Such negotiatory questions and uptake often led to student-initiated discussion and meaningful classroom dialogues.

In sum, two important implications can be drawn from the classroom research on questioning. First, open-ended questions, or authentic (Nystrand et al., 2003), negotiatory questions (Wells & Arauz, 2006) that focus on eliciting and extending student ideas, tend to be more conducive to productive discussion than close-ended, known information questions that seek predetermined correct answers. Second, although researchers have named the notion of contingency (Boyd & Rubin, 2006) differently, such as reflective toss (van

Zee & Minstrell, 1997), uptake (Nystrand et al., 2003), and contingent and nested queries (Roth, 1996), they generally agree that questions that are contingent on previous student utterances have great potential to promote rich discussions. Correspondingly, research on questioning in PBL facilitation should not only examine the types of questions being asked, but also the contingency of the questions on previous utterances.

In addition, much of what has been learned about questioning in classroom is based on studies of questioning practice of experienced teachers. For example, the study of van Zee and Minstrell (1997) focused on an experienced high school physics teacher; Boyd and Rubin (2006) focused on an experienced fourth- and fifth-grade ELL teacher; Roth (1996) studied an expert elementary teacher. Other studies focused on several experienced teachers (e.g., van Zee et al., 2001; Chin, 2007). Similarly, to improve PBL facilitation, the field can benefit from studies that examine questioning practice of experienced facilitators.

Using questioning to facilitate discussion in problem-based learning

There have been relatively few detailed analyses of PBL facilitation. One such example is a study by Hmelo-Silver and Barrows (2008) that analyzed two PBL group meetings guided by an experienced facilitator, in which five second-year medical students discussed a clinic problem concerning pernicious anemia. The authors differentiated the questions and statements made by the students and the facilitator. Three types of questions raised in discussion were categorized, including short-answer questions, long-answer questions, and task oriented and meta questions. They found that the facilitator asked a total of 343 questions in the two PBL meetings. Specifically, the facilitator asked short-answer questions (11%) to focus student attention, long-answer questions (13%) to push for clarifications and elaborations, and meta questions (75%) to evaluate hypotheses, check understanding, and monitor group dynamics.

The studies by Hmelo-Silver and Barrows (2006; 2008) made an important contribution to understanding the complexity of effective facilitation. However, the framework that Hmelo-Silver and Barrows (2008) used to characterize the facilitator's questioning was mainly originated from the question taxonomy developed by Graesser and Person (1994), with an addition of task-oriented and meta questions. Graesser and Person's taxonomy was developed to classify the types of questions asked during one-on-one tutoring sessions, in which the student tutors had only a modest amount of tutoring experience. We argue that small group discussion is different from conversation in one-on-one tutoring, and questioning by experienced facilitators is different from questioning by inexperienced student tutors. Therefore, new research is needed to develop a questioning framework that is sensitive to the context of PBL.

In addition, in their studies, the students had used PBL curricula for two years, so they were experienced with the PBL process. Yet, it remains unclear how to facilitate learners who are new to PBL. Moreover, most PBL studies, including the few that focused on facilitators' questioning, were conducted in medical education, which is not surprising considering that PBL was originated in medical schools. However, as the use of PBL is increasingly expanding in other fields, more studies on PBL facilitation in other contexts are clearly needed.

In this study, we examined questioning in PBL facilitation in the context of teacher professional development (PD). We designed a professional development model using the PBL approach to improve teachers' content knowledge and pedagogical content knowledge. This PD model included a two-week summer workshop and a year-long action research project. In summer, the first week focused on developing teachers' content knowledge by using the PBL process to solve science problems in areas such as physics, earth science and biology. In the second week, teachers used the PBL process to analyze teaching problems developed by the PD designers. During the school year, teachers conducted an action research project to investigate a problem from their own classroom practice. This PD model, with some variations, had been implemented for four years to four cohorts of teachers. Drawing on data collected from the second year, this study focused on the second week in summer when teachers analyzed teaching problems guided by facilitators. We asked two research questions: What types of questions did experienced facilitators ask to promote discussion of science teaching problems in professional development? How were the questions contingent on teachers' ideas in previous utterances?

Methods

Participants

Participants were six facilitators who paired up to facilitate two groups of teachers using the same teaching problem, as shown in table 1. One served as the lead facilitator with the other as assistant. The lead facilitator assumed major responsibility for guiding the group discussion, while the assistant facilitator mainly helped to record teachers' ideas on charts and sometimes asked questions or made statements. On average, the lead facilitators used about 32% of speaking turns in the group meetings, and assistant facilitators used about 8%. A total of 35 K-12 science teachers participated in the study, including 14 elementary teachers, 13 middle school teachers, and 8 high school teachers. Of the 35 teachers, 12 had 1-3 years of teaching experience, 10 had 4-10 years, and 13 had 11 or more years.

Except for one assistant facilitator (Facilitator 4), who was a doctoral student with five years of teaching experience, the facilitators were experienced science teachers or teacher educators, with teaching experience ranging from 15 to 34 years. Of more than 20 facilitators who were involved in the PD, these five facilitators were the leading designers and implementers. In the first year of the PD project, all facilitators received training from

PBL experts from the medical school at a large Midwestern university. They also observed PBL meetings in the medical school. Prior to the summer workshop, they practiced facilitation of content and pedagogical problems during weekly facilitator meetings. Because of the prominent role that the lead facilitators played in guiding the group discussions, we describe in detail their backgrounds in the following paragraph. Overall, given their extensive experience in science teaching, leading small group discussions, using PBL or inquiry-based teaching, and facilitating teacher professional development, we considered them to be experienced facilitators.

Facilitator 1 held a doctoral degree in education and had 25 years of teaching experience, including 7 years at the high school level and 18 years at the college level. She had led small group discussions in multiple professional development projects. She had also used PBL in her preservice teacher education courses for two years. Facilitator 2 held a doctoral degree in biochemistry and had 15 years of teaching experience, including 2 years at the middle school level and 13 years at a large Midwestern university. She had also facilitated multiple professional development sessions and had implemented PBL in her science methods courses for preservice teachers for two years. Facilitator 3 held a master degree in curriculum and instruction and had 34 years of teaching experience, including 29 years at the high school level and 5 years at a large Midwestern university. She had used an approach similar to PBL in her teaching for more than 20 years and had led multiple professional development workshops. She was also director of a state-wide nonprofit organization that involved more than 550 middle schools and high schools in its science tournament events.

Problems

Three instructional problems related to science teaching were used in this study, as shown in the appendix. In a problem called *Circuits,*[1] the central issue was how to help students move from vague ideas to scientific understanding of electric circuits. In a problem called

Table 1. Facilitators, problems and groups

Lead facilitator	Assistant facilitator	Problem	Day 1	Day 2
Facilitator 1	Facilitator 4	Circuits	Group 1 (9 teachers)	Group 2 (10 teachers)
Facilitator 2	Facilitator 5	Falling object	Group 2 (10 teachers)	Group 1 (9 teachers)
Facilitator 3	Facilitator 6	Weather map	Group 3 (8 teachers)	Group 4 (8 teachers)
Facilitator 7*	Facilitator 8*	Evolution	Group 4 (8 teachers)	Group 3 (8 teachers)

* We did not study Facilitators 7 and 8's questioning practice due to the poor quality of video recordings of their group meetings.

Falling object, the teacher in the scenario was struggling to help her students handle discrepant data from experiments of dropping objects to floor (Mikeska & Stanaway, 2006). In a problem called *Weather map,*[1] the main issue was how to design group tasks that could promote collaboration among students.

The group meeting started with reading the text-based problem scenario. Then the facilitators guided teachers to analyze the problem, discussing what was known (*facts*), what was unknown and needed to be learned (*learning issues*), and what accounted for the problematic phenomena (*hypotheses*). During discussion the assistant facilitator recorded teachers' ideas on charts. Next, teachers watched about 10 minutes of video vignettes concerning the classroom practice of the teacher in the problem scenario. The video clips were selected from published resources, from which facilitators designed relevant teaching problems. Teachers continued to discuss the problem after video watching, adding new facts, learning issues, or hypotheses. They then conducted individual research for about half an hour on some learning issues using online resources and books. Finally, they shared what they learned with the group and proposed solutions for the problem under consideration.

Data sources and analysis

The major data sources for this study were videotapes of the six PBL group meetings. Each group meeting lasted about 2-3 hours, resulting in a total of about 15 hours of videotapes. The videos and associated transcripts were entered into a database in Transana software, which allows synchronization between videos and transcripts. Analysis was based on the written transcripts, with the video used to examine specific segments. The transcripts were prepared and entered into a spreadsheet for analysis (Meyer & Avery, 2009). The entire turn of each speaker appeared in one row in one spreadsheet with a label for the speaker. A change of speaker generated a new speaking turn. The unit of analysis was the facilitators' speaking turn. Coding was applied in the same row but a different column in the spreadsheet.

Coding of facilitators' questioning strategies was an iterative process. The first author generated some initial categories of questioning when she observed some of the group meetings during the summer PD. After the videos of the six group discussions were transcribed, the first author reviewed the video and read the transcripts several times to get familiar with the content in the video. Interaction analysis (Jordan & Henderson, 1995) suggested that to facilitate video analysis, it is useful to identify the temporal structure of events in the video. Accordingly, the transcript of each group meeting was parsed into major phases including getting started, problem identification, problem analysis, and sharing research findings. The stage of teachers conducting individual research on learning issues was not videotaped. We identified facilitators' questions in each phase.

Nonetheless, problem analysis was the major phase in each group meeting and consumed the majority of facilitators' speaking turns.

In labeling questions in the transcripts, we included all facilitators' utterances that contained a grammatical form of questions, for example, beginning with interrogative words such as what, when, where, why, who, how, do/does, and are/am/is, or ended with a rising intonation, such as "other ideas?" Sometimes a question took the form of a state-

Table 2. Coding scheme for different types of questioning

Type of questioning	Description	Example
More frequent		
Soliciting ideas	Solicit ideas from the whole group on problems, facts, hypotheses, learning issues, research findings, and recommendations.	F: Any facts, observations or learning issues? F: Any other ideas?
Reframing ideas	Reframe a teacher's idea into a learning issue or hypothesis, or occasionally a problem or a fact, which mainly occurred in the problem analysis phrase.	F: Is that a learning issue? F: I am hearing an if/then statement. Because?
Clarifying ideas	Ask teachers to clarify their idea that was unclear to the facilitator.	T: So, as the person plan the inquiry, then present it, then initiate... F: What does it mean by present?
Pushing for elaboration	Ask teachers to elaborate on an idea.	F: I'd like to push your thoughts. F: I am not sure I understand that. Can you elaborate that?
Checking for interpretation	Ask a teacher to confirm whether a facilitator's interpretation of his or her ideas was accurate.	F: Is that what you are saying? F: Did I restate that OK?
Less frequent		
Calling on individuals	Invite responses from an individual teacher, to engage less vocal teachers in the discussion.	F: Mindy, what do you think about this?
Connecting to practice	Ask teachers to share experience on how to handle problems in their practice.	F: How do you handle that in the classroom? What do you do?
Tossing back	Throw a question that was addressed to a facilitator back to the group.	F: Can anyone answer that question?

T=Teacher; F=Facilitator

ment, such as "tell me more about it." All facilitators' questions were identified and coded except for procedural questions, such as questions that facilitators asked a teacher to read aloud the problem scenario, to repeat what he or she just said, and to assign learning issues for individual research. We also did not code instances in which facilitators called a teacher's name, who had already indicated an intention to talk, to grant him or her a speaking turn. These questions helped to maintain the process but did not bear much pedagogical connotations and only occurred a few times in one group discussion. In total we coded 435 facilitators' questions in the six discussions.

Through multiple viewings and readings, the first author developed an initial coding scheme to characterize the types of questions asked by the facilitators. The scheme was discussed in the project research meetings, in which other researchers provided feedback on the scheme. The first author used the refined coding scheme, as shown in table 2, to code all of the facilitators' questions identified. Another researcher who was familiar with the coding scheme independently coded 17% of entire dataset and the inter-rater reliability was 91%. Disagreement was resolved through discussion and video viewing.

We identified five types of questions that occurred relatively frequently (greater than 10% of total questions) and three types of questions less frequently (lower than 2%). In naming the questions, we considered both the context of this study and relevant literature. For example, we found facilitators frequently asked one type of question in the phases of problem identification, problem analysis, and sharing research findings to solicit ideas from the group. Van Zee et al. (2001) described a similar type of question that teachers asked to elicit students' experiences. Thus we labeled this type of questioning "soliciting ideas."

Coding for contingency was relatively straightforward and was conducted by the first author only. Similar to what Boyd and Rubin (2006) reported, the process of determining a question's contingency "was rarely difficult" (p. 152), as the contingency of a facilitator's question was often inherent in the type of question. For example, the questions that facilitators asked teachers to clarify or elaborate on ideas were always contingent on teachers' previous utterances. Through contingency analysis, we found that facilitators often asked a sequence of contingent questions to access and advance teachers' ideas.

In addition, at the end of the summer PD, a questionnaire was administered to 35 teachers to measure how well the PD was implemented, in which facilitation was one of the PD components that was evaluated (Science and Mathematics Program Improvement, 2006). From the survey, we identified items related to the PD objectives and the performance of facilitators. We present descriptive data such as mean scores and standard deviations based on teachers' ratings on those items on a 5-point Likert scale, along with examples of teachers' comments. Teachers' evaluation was one way to triangulate the finding of facilitators' questioning practice as the ultimate goal of facilitators' discourse moves was to achieve the PD objectives.

Results

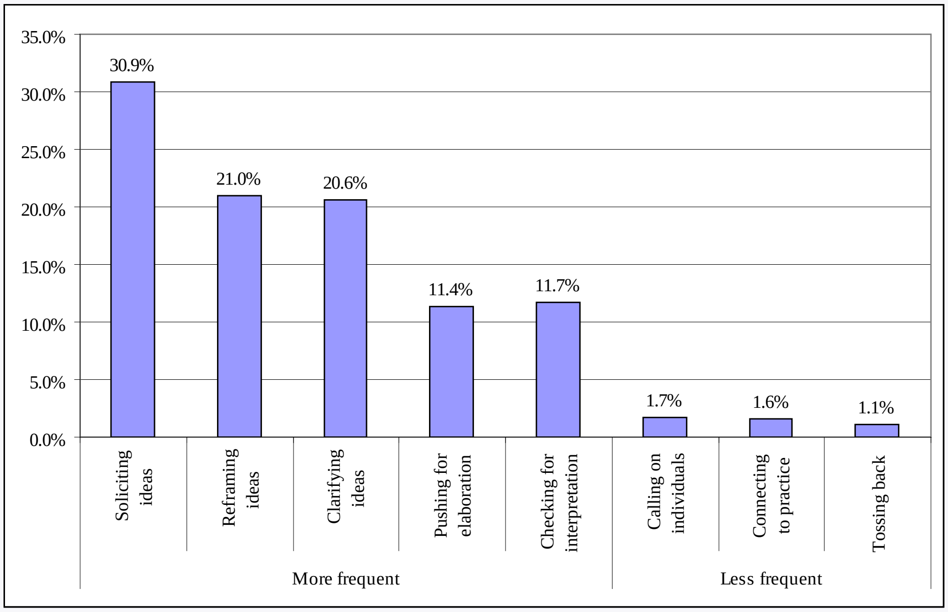
Questioning was frequently used by the facilitators in each of the six PBL sessions we studied. The facilitators asked questions to access, probe, and deepen teacher thinking. Specifically, we found the following types of questioning commonly used in all sessions: 1) soliciting ideas, 2) reframing ideas, 3) clarifying ideas, 4) pushing for elaboration, and 5)

Table 3. The percentages of questioning strategies used by facilitators in the six PBL sessions

Strategy	Circuits 1		Circuits 2		Falling object 1		Falling object 2		Weather map 1		Weather map 2	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
More frequent												
Soliciting ideas	28	27.7%	20	27.4%	22	36.7%	29	33.3%	23	36.5%	12	23.5%
Reframing ideas	28	27.7%	20	27.4%	5	8.3%	7	8.0%	11	17.5%	19	37.3%
Clarifying ideas	12	11.9%	16	21.9%	14	23.3%	14	16.1%	18	28.6%	11	21.6%
Pushing for elaboration	16	15.8%	8	11.0%	9	15.0%	15	17.2%	1	1.6%	4	7.8%
Checking for interpretation	8	7.9%	9	12.3%	8	13.3%	17	19.5%	6	9.5%	4	7.8%
Less frequent												
Calling on individuals	4	4.0%	0	0.0%	2	3.3%	1	1.1%	1	1.6%	0	0.0%
Connecting to practice	5	5.0%	0	0.0%	0	0.0%	4	4.6%	0	0.0%	0	0.0%
Tossing back	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3	4.8%	1	2.0%
Total	101		73		60		87		63		51	

Freq. = Frequency; %=Percentage of questions in total

Figure 1. Average percentage of questioning types used by facilitators in the six PBL sessions



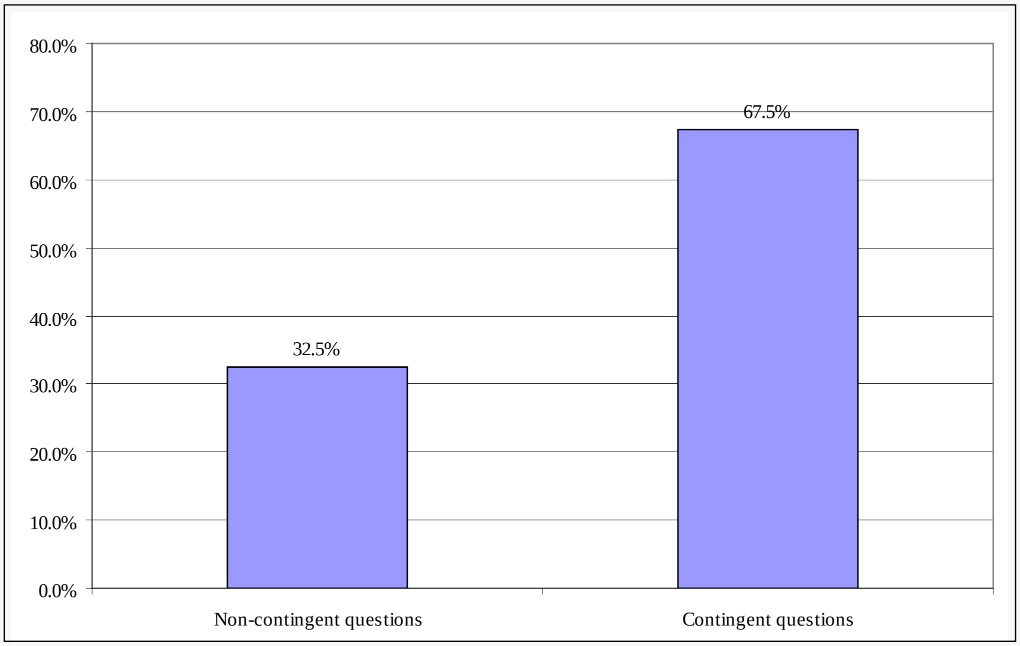
checking for interpretation. As shown in table 3 and figure 1, these five types of questioning accounted for more than 90% of total questions asked by the facilitators.

In addition, the following types of questioning either appeared less frequently or were used only by some facilitators in some sessions: 6) calling on individuals, 7) connecting to practice, and 8) tossing back. Although these questions were infrequently asked overall, they still had important pedagogical value in guiding the PBL discussion. Facilitators asked these questions to engage less vocal teachers, to connect to classroom practice, and to maintain a role as facilitators rather than content experts.

Figure 1 shows the average frequency of different questioning types. Figure 2 shows the percentage of contingent questions and noncontingent questions. About two thirds of facilitators' questions were contingent questions. Specifically, of the eight types of questions, soliciting ideas (from the group) and calling on individuals were not contingent on previous teachers' utterances. Questions of reframing ideas, clarifying ideas, pushing for elaboration, checking for interpretation, connecting to practice, and tossing back were contingent upon previous teachers' utterances.

In addition, the content of questions of soliciting ideas and reframing ideas were unique to PBL discourse. In other types of discourse, facilitators or teachers could also solicit and reframe ideas, but not necessarily ideas on problem analysis and reasoning. Also, reframing ideas mainly occurred in the problem analysis phase, while other questions

Figure 2. Average percentage of contingent and non-contingent questioning types used by facilitators in the six PBL sessions



(Note. Noncontingent questions included Soliciting ideas and Calling on individuals. Contingent questions included Reframing ideas, Clarifying ideas, Pushing for elaboration, Checking for interpretation, Connecting to practice, and Tossing back.)

Table 4. Summary of questioning strategies used by facilitators in the six PBL sessions

Type	Frequency	Contingency	Uniqueness of PBL discourse	Phase
Soliciting ideas	Frequent	Non-contingent	Unique	All*
Reframing ideas	Frequent	Contingent	Unique	Problem analysis
Clarifying ideas	Frequent	Contingent	General	All
Pushing for elaboration	Frequent	Contingent	General	All
Checking for interpretation	Frequent	Contingent	General	All
Calling on individuals	Infrequent	Non-contingent	General	All
Connecting to practice	Infrequent	Contingent	General	All
Tossing back	Infrequent	Contingent	General	All

* All refers to phases of problem identification, problem analysis, and sharing research findings. We did not study the individual research phase.

could occur in all phases. Table 4 summarizes the characteristics of different questions in terms of type, frequency, contingency, uniqueness to PBL discourse, and phase.

Next, we explain each type of questions and provide illustrative examples. Previous research defined productive discussion as involving three or more participants and lasting half a minute or longer (Nystrand et al., 2003). Given space limitations, we provide one such episode for the major types of questions to show that the facilitators' questions had potential to stimulate productive discussion. Pseudonyms were used for teachers.

Soliciting ideas

Questioning to solicit ideas was frequently used by the facilitators at each PBL phase to start, continue, or redirect a discussion. However, facilitators did not just solicit ideas in general, but ideas that reflected characteristics of PBL, that is, ideas on problems, facts, learning issues, hypotheses, research findings, and recommendations. It was used at the beginning of a PBL session to start a discussion by asking teachers to restate the problem, to identify facts, or to generate learning issues and hypotheses. Soliciting new ideas was also used to continue discussion. In general, this type of question was not contingent on previous teachers' utterances. It often signaled a transition to a new discussion topic.

First, at the beginning of a PBL session, usually after the group read the text-based problem scenario, facilitators asked the group to clarify the problem, as shown in the following example. Because PBL often starts with an ill-structured problem, clarification of the problem at the outset is critical, which directly influences the subsequent discussion.

> Facilitator 2: Let's restate the problem first. Let's agree on what the problem is. What is Nancy (the case teacher) asking us? [Falling object 1]

Second, during the problem analysis phase, facilitators asked questions to solicit teachers' ideas about facts, learning issues, and hypotheses in relation to the problem, as shown below. These questions often started a discussion effectively.

> Facilitator 1: Are there some learning issues that you'd like to address or some hypotheses? [Circuits 2]

Third, when discussion appeared to have reached an impasse, facilitators often initiated another call for ideas on facts, learning issues, or hypotheses, commonly expressed as "What else do we know?" or "Any other ideas?" Depending on the group dynamics, facilitators could ask these questions several times to continue the discussion.

Finally, in the sharing research phase, facilitators asked questions to solicit findings about the learning issues that teachers studied. Facilitators often named a specific learning issue (e.g., checking students' understanding) and asked the group for responses.

> Facilitator 3: Anybody else came across anything that deals with helping me check my students' understanding or anything else? [Weather map 2]

In sum, questions of soliciting ideas were used in each PBL phase to initiate and continue discussion. These questions helped to access teacher thinking and make it explicit, which laid the groundwork for further clarification and elaboration. Facilitators also used this type of question to structure a session and align the discussion with PBL discourse, which was characterized by problem identification, problem analysis, identifying knowledge deficits, and reasoning through hypothesizing.

Reframing ideas

Reframing ideas referred to the questions that facilitators asked to frame a teacher's idea as a learning issue or a hypothesis, and occasionally a fact, or a problem. Because teachers in this study were new to PBL, they were unfamiliar with the process of forming learning issues or developing hypotheses. As a result, teachers themselves rarely spontaneously posed a learning issue or hypothesis. Typically, facilitators recognized an idea emerged in discussion as a potential learning issue or hypothesis and asked teachers to confirm or restate. The reframing questions were often expressed as: Is that a learning issue (or hypothesis)? Or, how could you rephrase it as a learning issue (or hypothesis)? This type of question almost exclusively occurred in the problem analysis phase.

One such example was from Circuits 1. After Karen raised an idea of how to help students develop an understanding from doing the circuits activities, Facilitator 1 asked if it could be a learning issue. Nina then further explained the idea.

> Karen: Well, they had all of these activities so that, with the activities, how do you then make it an understanding of the current, of the circuits?
> Facilitator 1: So, is that a learning issue?
> Nina: You want to know how to apply those together if you want to connect them.

A critical practice in the PBL discussion was to develop hypotheses, which included three parts of pedagogical reasoning: If (a condition or solution presents), then (expected results will show), because (reasons that the condition or solution will lead to the results). Teachers often had difficulty articulating a complete hypothesis, particularly the "because" part. Therefore, facilitators often pushed teachers to explain why a condition or solution might lead to the expected results. One such example was from Circuits 1, in which Facilitator 1 reframed teachers' idea into a hypothesis (turn 6) and pushed teachers to complete the "because" part of a hypothesis. The practice of articulating "because" helped teachers deepen their original thinking.

Episode 1 (2.5 minutes): "If…, then…, because…?" (Circuits 1)

1. George: I have another question. I'm sorry, but do we see hands when she [the teacher in the video] asked the questions or did she just call on people?
2. Bob: She just called on people.
3. George: And that's what I think the difference too, because she was making them be responsible. Ok, let the certain person answer all the questions or whatever.
4. Kate: She gave them the opportunity to respond.
5. George: Yeah, because they knew that they had to be on their toes or whatever.
6. Facilitator 1: So, that's really another hypothesis, isn't it? I heard an "if" and "then." I heard you say "if teachers call on students, then that makes them more responsible for their learning and being on task." Because?
7. George: They'll be prepared to be on their toes.
8. Karen: How do we give students time to formulate thinking about the learning issue?

…

9. Kate: Well, she gave them time to think and I'm making an assumption here that she might go back to them and say "Ok, were you right or were you wrong?" So students are given the opportunity to test their own hypothesis and come to their own conclusions, so they gain a greater understanding.
10. Facilitator 1: Because?
11. Kate: Because they had to find out the answer themselves.
12. George: Well, if she doesn't tell them the answer.
13. Bella: Because they've taken more responsibility.
14. Kate: And because they, yeah, they've taken a greater control in their learning.
15. Facilitator 1: That works nice. A greater control in their learning. Write that down.

Developing hypotheses and generating learning issues are critical skills in PBL, and these skills take time to develop. Because the teachers were inexperienced with the PBL approach, it was essential for the facilitators to model the process at the early stage.

Clarifying ideas

Questioning to clarify ideas was frequently used in each PBL session. The questions ranged from clarifying meaning of specific words to the whole utterance by a speaker. This type of question was often expressed as "What does it mean by…?" "Let's be more specific," or "I am not clear what you meant, could you tell me more?" The clarifying question was usually followed by teachers' clarification. The contingency of a clarifying question was inherent because facilitators had to refer to a teacher's idea in previous utterances to ask such a question.

The following excerpt from Weather map 2 illustrated how clarifying questions fostered meaningful discussion in problem analysis and eventually led to the development of an important learning issue. In this episode, Facilitator 3 played the role of the teacher in the video. First, a teacher, Kevin, made an observation that in the problem scenario there was no direction for group work. Two other teachers, Julie and Leslie, agreed with the idea and added to it. However, their statements were somewhat vague, so Facilitator 3 asked them to clarify their meaning (turn 7). Then Julie explained that although four students worked together as a group, their task was not collaborative in nature. Another teacher, Kara, paraphrased the idea that it was an individualized task which occurred in a group setting. Next, the group developed a learning issue of how to design a group task that could promote meaningful collaboration.

Episode 2 (1.5 minutes): Individual task in group work (Weather map 2)

1. Kevin: One thing I see in our problem too, is she asked them to get in a group and work, but there's no rubric, no directions on how to work, there's no leader, who's going to do the task, or there's just no clear directions on how they are supposed to work together in a group.
2. Facilitator 6: Kevin, phrase that as a problem.
3. Kevin: Problem, no directions for group.
4. Julie: Well, that is what I was thinking too, that they are working as a group but really individualize on an aspect.
5. Leslie: It looks like it could easily be an individual thing. And now you've got four kids sitting together.
6. Julie: Right.
7. Facilitator 3: See, now, let's focus on that a little bit, because I am not really clear by what you meant by that. Could you tell me more?
8. Julie: For me to look at this, I mean, I think that if one student can do it on their own without having to work with the three other students.
9. Facilitator 3: So my design of my [group] task isn't really [collaborative].
10. Julie: Right. Did each person have a different role and things like that? Did they have to gather different information?

11. Leslie: Or do you want them to [inaudible]?
12. Julie: Right. Some of the kids—I know that in my class some want to do it on their own because they want to get, you know they're going to put in all their work and they want to make certain they have it perfect, and, so,
13. Facilitator 6: Those are good thoughts, I'd I like to capture them too, so tell me what to write.
14. Kara: It's an individualized task but in a group setting.

It was very common that teachers' initial ideas tended to be vague and incomplete. Clarifying questions helped teachers articulate their thinking and develop complete and specific learning issues and hypotheses. Yet, facilitators should be mindful in deciding which ideas to focus on, and to what extent to push for clarification.

Pushing for elaboration

Unlike clarifying questions, which focused on helping teachers articulate their vague ideas, questions for elaboration aimed to deepen or expand teachers' original ideas, which were often clearly stated already. This type of question had great potential for stimulating rich discussion. The following excerpt was such an example, in which Facilitator 1 pushed teachers to elaborate on an idea that emerged in discussion. The original idea was about how the teacher in the problem scenario grouped students. Because grouping was a common problem facing teachers in their practice, the facilitator pushed teachers to elaborate on their ideas. Through elaboration, teachers shared multiple perspectives on dealing with the grouping problem.

Episode 3 (2.5 minutes): How did the teacher group students? (Circuits 2)

1. Lily: I wonder if she grouped students intentionally because I noticed one boy didn't get it and the other boy was explaining, and I wonder if she had students working together to help each other and then she was also coming in to help.
2. Facilitator 1: So is that a learning issue or is that, is that,
3. Lily: Oh, I think that is "what do you need to know." I think it would be interesting to know if that's part of the grouping.
4. Sarah: She needs to carry it further, like what they say in the parallel they don't share wires but they do share the same battery. Where is the "why" there? "Well, why would that make a difference?" "But why, why do you think that's," . . .
5. Facilitator 1: I'd like to push your thought.
6. Lily: Which part of our thought?
7. Facilitator 1: The last thought that you had, how does she group her students?
8. Lily: Yeah.

9. Facilitator 1: Is that really a learning issue that is worth some research? How is it you group students to affect relationships?
10. Lily: Yeah, because I think you group kids, but they help other kids. You know that kids aren't going to learn everything from you. Some are going to learn from other kids and they are going to learn by doing and,
11. Facilitator 1: Right.
12. Lily: And then there comes that issue where kids choose their groups for them and then do you want them at the same level? I mean it is,
13. Ariel. Sometimes you do want them at the same level like their reading group.
14. Lily: Yeah, but there are other times you want them to be, to help each other out. That was an interesting interaction [in the video] where one boy was explaining it, and I wonder if the other groups were like that.

… [More discussion on this topic was omitted due to space constraints.]

Checking for interpretation

This type of question was used after a facilitator restated a teacher's idea to confirm whether her interpretation was accurate. As shown in the following examples, these confirming questions were typically stated as: "Is that what you are thinking?" or "Is that what you said?"

Facilitator 1: Yes, that is powerful. So what we don't know helps drive us to learn. Is that what I heard you just say? [Circuits 1]

Facilitator 5: So, if there is some discrepancy, then do a whole group [discussion] again. Is that what you are thinking? [Falling object 1]

The checking for interpretation questions seemed to contribute to two goals. First, in combination with a paraphrase, it helped to clarify meaning to other teachers. Second, it showed respect to the teachers by asking them to confirm whether the restatement was accurate, which might enhance the teachers' sense of ownership for the original idea.

In addition to the questions above, facilitators sometimes called on individual teachers to engage less vocal members in discussion (e.g., "So, Mike, did you have things that you wanted to get up here?") or to seek help from strong members (e.g., "George, you want to help out?"). Also, occasionally, facilitators connected discussion to teachers' classroom practice by asking: How do you handle this problem in your own teaching? These questions helped to make the discussion relevant to teachers. Typically, the facilitators recognized an instructional issue that emerged in discussion as important and asked the teachers how they handled it in their classroom. In addition, teachers sometimes asked a facilitator a content question. However, the facilitator did not answer it herself but asked the group to respond, which we referred to as tossing back. Tossing back was a straightforward but useful technique that facilitators could use when they did not want to be seen as "content experts." Research showed that such an expert role had a detrimental effect on group discussion (Kaufmann & Holmes, 1998). Participants were less willing to contribute ideas when they considered their facilitator experts.

Teachers' evaluation of the group discussion and facilitation

According to the evaluation survey, the teachers perceived the major objectives of the PBL sessions were well met, as shown in table 5. Specifically, the teachers reported that the PD increased their reasoning skills, encouraged them to think deeply about their teaching, and improved their ability to identify issues and challenges in science teaching and apply appropriate solutions. They also felt prepared to use PBL as a tool to analyze their own science teaching practices. In addition, teachers highly valued the performance of facilitators. They reported that the facilitators were effective in organizing sessions so that they were actively involved and the facilitators were effective in communicating ideas and issues.

Discussion

In this study we described a set of questions that PBL facilitators asked to promote discussion of teaching problems in professional development for science teachers. Through multiple examples, we illustrated the context under which each type of question functioned. In sum, facilitator questioning played a vital role in getting discussion started and advancing discussion. Next, we discuss the findings around three themes.

First, facilitators structured the discussion in line with PBL discourse that centered on problem analysis and pedagogical reasoning through soliciting and reframing ideas on problems, facts, learning issues, hypotheses, findings, and recommendations. Such questions made the discussion in this study distinct from video-supported case discussion in other PD contexts (e.g., Borko, Jacobs, Eiteljorg, & Pittman, 2008; Sherin & van Es, 2009). For example, in the study of Sherin and van Es (2009), the facilitators primarily focused on sharpening teachers' "professional vision"—the ability to notice student thinking. Such discussion was not problem-driven and did not necessarily involve identifying knowledge gaps (learning issues).

This study provides an interesting comparison to the study of Hmelo-Silver and Barrows (2008), in which the medical students were experienced PBL learners. Teachers in this study were new to PBL. For most of them, it was the first time that they encountered the PBL approach. Thus, they were unfamiliar with the PBL process, such as generating learning issues or developing hypotheses. As a result, facilitators needed to help them reframe their ideas into learning issues and hypotheses. Hmelo-Silver and Barrows (2008) characterized the facilitator's questions of defining learning issues as self-directed learning. They found about 5% of the facilitator's questions were related to self-directed learning, while in this study we found about 21% of facilitators' questions were reframing questions. The findings of these two studies suggest that facilitators' guidance should be flexible

Table 5. Teachers' evaluation on learning and facilitation (N=35)

Questionnaire items	Mean	Std.	Teachers' comments
Increasing reasoning skills and encouraging teachers to think deeply about their teaching.[1]	4.7	.64	▪ I examined each piece of my teaching style and assumptions closely. ▪ I thought more deeply at this conference than any other PD I have done!
Identifying issues and challenges in science teaching and applying appropriate solutions.[1]	4.4	.78	▪ It really makes you look at your strategies and how you can improve them. ▪ Requires thinking, explaining, listening, and researching. A good situation.
Increasing participants' abilities to analyze and refine science teaching practices using teaching problems.[1]	4.4	.84	▪ We had to think a lot about our current practice. ▪ I think I am better able to analyze than when I started.
Applying problem-based learning and science knowledge to teaching problems.[1]	4.2	.86	▪ Develops deeper understanding ▪ This is a work in progress. I am working on it and thinking how. ▪ Too much information in too little time.
Providing a professional learning environment for teachers to acquire new knowledge of instructional practice.[1]	4.7	.66	▪ Awesome!! I wish the PDs at my district were half as good. ▪ Excellent at this. I think there is a learning community, a fun outlook, and facilitators that are knowledgeable and helpful.
Preparing participants to use problem-based learning as a tool to analyze their science teaching.[1]	4.1	.99	▪ I feel very confident. The facilitators walked us through the steps to analyze. ▪ I am fired up to go to my classroom, video myself and analyze my strengths and weaknesses.
Facilitators were effective in communicating ideas and issues.[2]	4.7	.68	▪ I interacted with most of the facilitators and found them extremely positive, knowledgeable, and friendly. ▪ The facilitators were exceptional people with great ideas and empowered my own confidence in teaching science.
Facilitators were effective in organizing sessions so that I was actively involved.[2]	4.7	.68	▪ Everything was so well-organized. No time was wasted. ▪ We were all busy and valued.

1. Teachers were asked to rate to what degree each of the PD objectives was accomplished. 1=not achieved at all; 5=very well achieved.
2. Teachers were asked to rate to what degree they agreed with the statement. 1=strongly disagree; 5=strongly agree.

and take into account learners' prior knowledge and the stage of a PBL group. As shown in this study, perhaps facilitators need to provide considerable guidance to learners who have limited prior experience with PBL at an early stage of a PBL group. After learners gain more experience and are capable of conducting problem analysis and reasoning independently, facilitators can gradually fade their scaffolding. As shown in the study of Hmelo-Silver and Barrows (2008), experienced PBL students were more able to develop hypotheses and generate learning issues without the facilitator's prompting. Students were also more able to sustain their discussion without the facilitator's involvement.

Second, facilitators in this study helped teachers develop ideas through reframing, clarification and elaboration. Facilitators asked contingent questions that were built on teachers' original ideas. The majority (67%) of facilitators' questions in this study were contingent on teachers' ideas. Such contingent questions helped teachers articulate vague thoughts, consider alternative perspectives, and engage in pedagogical reasoning. Classroom research on questioning showed that contingency is an important feature of teacher questions that lead to productive classroom discussion (Boyd & Rubin, 2006; Nystrand et al., 2003). This study showed that, like experienced teachers in leading classroom discussion, PBL facilitators also asked contingent questions that were built on participants' responses.

Regarding the finding that facilitators asked different types of questions, one naturally wonders, "Which question is more effective?" However, this study suggests that different types of questions have different functions. For example, questions of soliciting ideas helped to get discussion started. Questions of reframing ideas helped to structure the discussion in line with PBL discourse. Questions of clarifying and elaborating ideas helped to improve weak and incomplete ideas. Thus, perhaps a more productive question about questioning is, "How should questions work together to advance ideas?" This study suggests a sequence of questions that facilitators can ask to access, probe, clarify and deepen teacher thinking. In short, facilitators can access teachers' initial thinking by asking questions to solicit ideas, clarify thinking by asking them to articulate, and deepen thinking by asking them to explain or elaborate.

Third, facilitators in this study rarely evaluated teachers' responses as right or wrong, perhaps because the problem was fairly ill structured, and facilitators' questions were open ended that did not necessarily have a correct answer. Instead, they often interpreted teachers' ideas and asked them to confirm the accuracy of their interpretations. This follow-up move to participants' responses to their previous questions helped to break the IRE sequence found prevalent in classroom discourse (Lemke, 1990; Mehan, 1979). Such a follow-up move, together with other questioning strategies discussed earlier, had potential to promote dialogic discourse advocated by classroom discourse researchers (Wells & Arauz, 2006), as shown in the episodes we provided in the results section.

Some limitations of this study should be noted, however. First, this study is essentially a descriptive qualitative study based on a small sample size using a convenience sampling approach (Patton, 1990). We did not first evaluate each facilitator's questioning practice and then choose them to be the subjects of the study. We described what types of questions were asked under what contexts and provided illustrative examples. We did not assume every question was useful or even necessary. Although we presented teachers' evaluation as one way to triangulate the findings on facilitators' questioning practice, we acknowledge the limited nature of such self report data. It is possible that teachers did not improve their reasoning skills although they perceived so. Additional research is needed to determine to what extent the findings of this exploratory study apply to other contexts.

Nonetheless, few studies on PBL facilitation have been conducted outside medical education. This study contributes to the field by revealing a variety of questioning strategies that had potential to promote discussion for science teachers who were new to the PBL approach. In addition, the context of teacher professional development imposed tighter time constraints on implementing PBL than most medical education programs, in which medical students typically have an extended period (e.g., a semester) to study a PBL curriculum. In this study, teachers had to finish the entire PBL process, including problem identification, problem analysis, individual research, and problem solving within three hours. In this sense, PBL facilitation in professional development is even more challenging than in typical medical settings. This study illustrates a picture of what is possible in PBL facilitation through questioning with tight time constraints.

Because we only examined questioning in facilitation at an early stage of a PBL group, future research should investigate how facilitators gradually fade their scaffolding when a group becomes more experienced with the PBL process. Future research should also examine how group members acquire and internalize the questioning strategies used by facilitators and develop their own questioning skills.

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Note

1. The Circuits and Weather map problems were created by the facilitators in the PBL Project for Teachers, 2006.

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Appendix

Three teaching problems

Circuits and Pathways

Context: The principle of electricity was the focus for my group of 30 fourth grade students in a public elementary school in Castro Valley, California during the month of March. I began the unit with a questionnaire asking students, "Where in your house do you find electricity? How do you use it? What might happen if your flashlight stops working?" I started by having the students learn about things that were more familiar to them and then moved to more complex ideas. First, the students made posters of ways that they use electricity in their lives. Then, students experimented with a variety of materials and focused on one challenge: lighting a bulb using a battery, bulb, and wire. They also used a battery, wires, and motor to make the drive shaft on the motor turn in a clockwise and counterclockwise fashion. After that, they moved to learning about and constructing series and parallel circuits. My goal was for students to come away with an understanding of some of the basic principles of electricity, including how circuits work, how circuits do not work, and something about the flow of current, as well as have the experience of designing and carrying out their own experiments.

Objective: Students will be able to construct a simple electric circuit that provides a pathway so that energy can move between a source (battery) and an object (bulb and/or bell). Students will be able to identify and describe how various types of electrical circuits (i.e. series and parallel) provide a means of transferring and using electrical energy to produce light.

Teaching dilemma: I think that it's important for students to take responsibility for their own learning and to learn to think critically, to learn to question and to become excited about learning and excited about what they see happening in the world. When they're able to have their hands on the materials and when they're able to speak with one another, they're in control. After the students had an opportunity to create parallel and series circuits, they noticed that the bulbs in the parallel circuit were brighter than the bulbs in the series circuit. Asking the students to explain their thinking led to a variety of ideas for this observation.

Focus question: How might a teacher move his or her students from vague ideas to a more scientific understanding?

Product: A recommendation for how this teacher might move her students to a more scientific understanding of electricity.

How Things Move (Falling objects)

Context: As a first grade teacher, I try to embed process skills into our science investigations as often as possible. Making observations and drawing conclusions are two essential components of my county's science curriculum. I felt that they students would not be challenged by the county objectives that they be able to "give examples to demonstrate that things fall to the ground unless something holds them up" and to "describe the different ways that objects move (e.g. straight, round and round, fast and slow)" (Curriculum Framework, MCPS, 2001). I wanted them to go further than these basic objectives, to use their abilities to make observations and draw conclusions to delve deeper by asking "why" questions. I consulted the science specialist for ideas, and he suggested a classic experiment: Drop a flat piece of paper and a book at the same time from the same height, and then drop a crumpled piece of paper and a book at the same time from the same height, and compare the difference in results. That seemed perfect.

The students were comfortable both working in small groups with hands-on materials and sharing their thoughts and results in a whole-class setting, so I planned some of each for the activity. I assumed that they would first observe the book hitting the ground before the flat piece of paper, and then the crumpled paper and the book hitting the ground at the same time. I could then ask them to explain the difference in results, and I was interested to see how they would do. But the lesson did not work out quite as I planned.

Objective: Students will be able to communicate findings from group observations and investigations to the class and the teacher and provide supporting evidence when forming conclusions. Students will be able to describe different ways that objects move and give examples to demonstrate that things fall to the ground unless something holds them up.

Teaching dilemma: On the first day, the students made predictions for what they thought would happen when you drop a book and a piece of paper at the same time from the same height. On the second day, the students used the materials to complete their first part of their investigation in small groups (book and flat piece of paper) and then discussed what happened. However, the students returned with a variety of results from the same investigation. Most surprisingly, it seemed as though the students were accepting these findings with little controversy. How can the students make predictions that seem very logical and reasonable one day and then return with observed phenomena that seems to completely refute their sensible ideas the next day? How did they not question these observations? It seemed as though their sense-making was completely cast aside as they shared their observations with the group.

Focus question: What interactions (student to student, student to teacher, and teacher to student) might you set-up to resolve discrepant data?

Product: A recommendation of how this teacher might facilitate the conversation and learning experience to help students notice and resolve discrepant data.

Weather Map

Context: Eighth graders in the state of Michigan are required to take a state assessment test for science and social studies every October based on state standards and benchmarks. The meteorology section of the science test requires students to analyze weather maps. I teach in a small rural school district and one of the challenges we face is the influx of transient students. This was a group of students who found learning very challenging. As a result, I felt I needed to keep the frustration level low. To do this, I reviewed much of what had been taught in previous classes on a daily basis.

In this lesson, students are finishing a unit on Meteorology. The two-day culminating activity was designed to allow students an opportunity to apply what they had learned by creating a weather map. Students used an information sheet of weather data from a variety of U.S. cities and a printed satellite weather map from a popular cable weather channel to complete a weather map.

Objective: Students, working as a team of meteorologists will be able to create a national weather map, correctly placing weather stations models at the appropriate cities, as well as warm and cold fronts, precipitation, and high and low pressure centers. They will be able to forecast the weather for the twelve cities for the following day.

Teaching dilemma: I use many different resources when I teach a unit. For my meteorology unit, I got information from the National Oceanographic and Atmospheric Administration, cable weather stations, teacher resources, and other Internet resources. Unfortunately, not all the information is exactly the same, so students are often expected to interpret the similarities of each of the different resources. I believe this encourages them to be more flexible and better problem solvers when trying to accomplish a task. Prior to staring work on this activity, the students were directed to work as a group on their weather symbol diagrams. However, as I observed the students, they were interacting only occasionally by talking quietly or sharing maps.

Focus question: How could this task have included structures that might have stimulated more collaboration among students?

Product: A recommendation of how this teacher might structure this activity to promote more collaboration among students.