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Teacher Questioning in Science Classrooms: Approaches that Stimulate Productive Thinking

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Abstract: The purpose of this study was to find out how teachers use questions in classroom discourse to scaffold student thinking and help students construct scientific knowledge. The study was conducted in large-class settings where the medium of instruction was English although the students were non-native speakers of the language. Six teachers teaching grade 7 science classes from four schools participated in the study. Thirty-six lessons covering a range of topics were observed across a variety of lesson structures such as expository teaching, whole-class discussions, and laboratory work. The lessons were audiotaped and videotaped. Verbal transcripts of classroom discourse were analyzed interpretively. Particular attention was paid to questioning exchanges that stimulated productive thinking in students, as manifested by their verbal responses. A framework was developed that included four questioning approaches adopted by the teachers. This included Socratic questioning, verbal jigsaw, semantic tapestry, and framing. This paper describes these various questioning approaches, their features, and the conditions under which they were used. It also discusses the implications of these approaches for instructional practice. The findings from this study have potential in translating research insights into practical advice for teachers regarding tactical moves in classroom discourse, and provide guidelines for teachers to increase their repertoire of questioning skills. © 2007 Wiley Periodicals, Inc. J Res Sci Teach 44: 815–843, 2007

Introduction

When students learn science, they construct meanings and develop understandings in a social context (Duit & Treagust, 1998). Much of this meaning-making occurs through classroom discourse as part of teacher talk and teacher–student interactions. Because teacher questions are a frequent component of classroom talk, they play an important role in determining the nature of discourse during science instruction. The kinds of questions that teachers ask and the way teachers ask these questions can, to some extent, influence the type of cognitive processes that students

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engage in as they grapple with the process of constructing scientific knowledge. Thus, the role of teacher questions in science talk is a fruitful area to explore, in our search for a better understanding of how students construct knowledge through verbal discourse in classroom settings.

This study investigates questioning-based discourse practices in science classrooms and how knowledge is co-constructed in science classrooms through the interaction between teacher and students across a number of classroom activities. It aims to identify different ways of teacher questioning that encourage productive thinking in students.

Theoretical Underpinnings

The principal theoretical framework underlying this study is social constructivism, which focuses on how knowledge is constructed in the social context of the classroom through language and other semiotic means. Central to this is the idea that scientific conceptual knowledge first appears between people on an interpsychological plane and then inside the learner on an intrapsychological plane (Vygotsky, 1978). The notion of the teacher assisting student performance through the ‘‘zone of proximal development’’ suggests that teachers can guide the discourse of the interpsychological plane to support student learning. As questions are a key component of classroom discourse, this suggests that teacher’s questions have potential as a psychological tool in mediating students’ knowledge construction.

Classroom discourse can be analyzed in terms of its authoritative and dialogic functions (Scott, 1998). In authoritative discourse, the teacher intends to convey information—thus, teacher talk has a transmissive function. Teacher talk often involves factual statements, reviews, and instructional questions, and students’ responses to the teacher’s questions typically consist of single, detached words. On the other hand, in dialogic discourse, the teacher encourages students to put forward their ideas, explore and debate points of view, and students’ responses are often tentative suggestions based on open or genuine questions, spontaneous, and expressed in whole phrases or sentences. The styles of interpsychological functioning employed in classroom discourse will be reflected in subsequent intrapsychological functioning (Wertsch & Toma, 1991, cited in Scott, 1998). This implies that when students engage in dialogic discourse that fosters more generative thinking, good habits of mind such as questioning and relating ideas are rehearsed on the social plane. This might then form the basis of active, analytic, individual thought (Scott, 1998). While dialogic discourse allows students to argue and justify their ideas, the authoritative discourse also has its place in the classroom, particularly when the already constructed shared knowledge needs to be emphasized. Indeed, an alternation between these two types of discourse is important for developing conceptual thinking on the intrapsychological plane (Mortimer, 1998). Scott (1998) referred to this alternation as ‘‘rhythm of the discourse,’’ and suggested that learning will be enhanced through a balance between presenting information and allowing exploration of ideas.

Classroom Interaction and Discourse in Science

Teaching science involves introducing students to the social language of school science. The teacher must make the scientific ideas available on the social plane of the classroom, assist students in making sense of and internalizing those ideas, and support students in applying the ideas. In doing this, she needs to draw upon students’ prior and everyday views of the topic, convince students of the scientific views, as well as monitor and respond to students’ understandings (Mortimer & Scott, 2003).

In their ‘‘flow of discourse’’ analytical framework, Mortimer and Scott (2003) discussed their concept of communicative approach, which focuses on whether or not the teacher takes account of students’ ideas and whether she interacts with students. This framework consists of four categories generated from the combinations of two dimensions (dialogic–authoritative and interactive–non-interactive) along which classroom discourse can be analyzed. The dialogic approach recognizes more than one point of view, while the authoritative approach focuses on just one (the school science) point of view. The interactive approach allows for the participation of other people, but the non-interaction approach excludes them.

Thus, for the interactive/authoritative communicative approach, the teacher invites responses from students but discounts their ideas, as she focuses solely on the scientific idea. She typically leads students through a sequence of questions and answers with the aim of reaching one specific point of view. In contrast, for the interactive/dialogic approach, the teacher explores students’ views and takes account of them, even though they may be quite different from the scientific one. The non-interactive/authoritative approach is best represented by the formal lecture where the teacher presents normative ideas in a monologue. As for the non-interactive/dialogic approach, the teacher does not invite any turn-taking interaction with students but makes statements that address other points of view, in addition to the formal scientific one. The above authors identified the main forms of teacher interventions to be shaping ideas, selecting ideas, marking key ideas, sharing ideas, checking student ideas, and reviewing.

Different discourse practices and ways of speaking are manifested in different types of activities (van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001). During a lecture, the teacher expounds facts and procedures, and students are expected to listen. The teacher may ask and answer questions but student questions are rare (Dillon, 1988a). Instruction is primarily didactic via ‘‘teaching by telling’’ and the purpose is to deliver information as efficiently as possible. During a recitation, the teacher asks questions to check on student knowledge and understanding (Initiation), listens to students’ answers (Response), and assesses the correctness of these responses (Evaluation). This is the IRE structure (Mehan, 1979) or triadic dialogue (Lemke, 1990) that is predominant in classrooms, and the teacher’s questions are usually pitched at recall and lower-order thinking. It is sometimes known as the IRF representing initiation, response, and follow-up (Sinclair & Coulthard, 1975), as the third move may not necessarily be an explicit evaluation.

During a guided discussion, the teacher asks conceptual questions to elicit students’ ideas and facilitate productive thinking, invites and welcomes students’ responses and questions, provides on-going assessment by commenting on students’ responses, and encourages multiple responses. All these are done with the aim of helping students construct knowledge in the spirit of inquiry and constructivism (e.g., Roth, 1996; Settlage, 1995; van Zee & Minstrell, 1997a,b).

Teacher Questioning

Teacher questioning is a prominent feature of classroom talk. Questions can stimulate student thinking and provide feedback for the teacher about students’ understanding. Much of the early studies on teacher questioning (e.g., Dantonio & Paradise, 1988; Mill, Rice, Berliner, & Rousseau, 1980; Redfield & Rousseau, 1981; Winne, 1979) were conducted using a process-product paradigm to study the relationship between teacher questioning and student achievement. However, these have produced mixed findings. Carlsen (1991) proposed a socio-linguistic framework for research into teacher questioning that would illuminate contextual issues that cannot be addressed by studies based on a process-product paradigm. This framework consists of three features: the context of questions, the content of questions, and the responses and reactions to questions.

Previous studies on teacher questioning focused on the recitation or the IRE (initiation, response, evaluation) pattern of discourse (Mehan, 1979) and the importance of wait time in increasing students' thoughtfulness (Rowe, 1986; Tobin, 1987). Dillon (1985, 1988b) discussed the lack of student active engagement when teachers asked too many questions based on the IRE format. He (Dillon, 1982) asserted that the prevalence of evaluative questions of the IRE format in classroom talk would be counterproductive to students articulating their thoughts.

The purpose of teacher questioning in traditional lessons is to evaluate what students know. The teacher asks a closed question that is basically information-seeking, that requires a predetermined short answer, and that is usually pitched at the recall or lower-order cognitive level. She then praises correct answers and corrects those that are wrong. Students are discouraged from articulating their thoughts. Their challenges to her questions are treated as a threat (Baird & Northfield, 1992). The teacher moves through a series of questions in accordance with a planned agenda. She is also the authority who asserts knowledge claims that she expects students to accept without debate on the basis of her authority (van Zee & Minstrell, 1997b).

However, in classrooms where the focus is on true dialogues (Lemke, 1990) or conceptual change using constructivist-based instructional approaches (Smith, Blakeslee, & Anderson, 1993), the nature of questioning is different. In such classes, the teacher's intent is to elicit what students think (such as their explanations and predictions, especially if these are different from what scientists think), encourage them to elaborate on their previous answers and ideas, and to help students construct conceptual knowledge. Thus, questioning is used to diagnose and extend students' ideas and to scaffold students' thinking. Such questions are more open requiring one- or two-sentence answers, and the teacher engages students in higher-order thinking (Baird & Northfield, 1992). Flexibility in questioning is needed as discussion proceeds. The teacher adjusts questioning to accommodate students' contributions and responds to students' thinking in a neutral rather than evaluative manner. She formulates questions in ways that shift authority for evaluating answers from herself as the teacher to all students who try to make sense of what their classmates are saying (van Zee & Minstrell, 1997b).

van Zee and Minstrell (1997b) described a particular kind of question, the ''reflective toss,'' which typically consists of a three-part structure comprising a student statement, teacher question, and additional student statements. The toss metaphor suggests a teacher ''catching'' the meaning of the student's prior utterance and ''throwing'' responsibility for thinking back to the student and all those present in class. The above authors proposed that this form of questioning may help teachers shift toward more reflective discourse that helps students to clarify their meanings, consider various points of view, and monitor their own thinking. Teaching strategies associated with reflective discourse included soliciting students' conceptions, restating student utterances in a neutral manner, using reflective questioning, and invoking silence to foster student thinking (van Zee & Minstrell, 1997a).

Mortimer and Scott (2003) expanded on the IRE or IRF structure by identifying the IRFRF chain where the elaborative feedback from the teacher is followed by a further response from a student. This form is typical of discourse that supports a dialogic interaction. As part of the feedback, the teacher could repeat a student's comment to encourage the student to continue, elaborate on the comment, or ask for elaboration. By establishing this pattern of discourse, the teacher is able to explore students' ideas.

Table 1 summarizes the differences between the nature of questioning in traditional versus constructivist or inquiry-based teaching (Baird & Northfield, 1992; Lemke, 1990; Mehan, 1979; Mortimer & Scott, 2003; van Zee & Minstrell, 1997b).

Table 1
Comparison of teacher questioning in traditional and constructivist teaching

	Traditional	Constructivist/Inquiry
Purpose of questioning	Evaluate what students know	Elicit what students think, encourage them to elaborate on their thinking, and help them construct conceptual knowledge
Structure of questioning sequence	IRE (teacher-student-teacher)	IRFRF chain Reflective toss (student-teacher-student)
Adjustments to teacher's agenda	Move through a series of questions in accordance with planned agenda	Adjust questioning to accommodate students' contributions and respond to students' thinking
Nature of questions and responses	Recall, lower order, closed with predetermined short answer	Open, engage students in taking more responsibility for thinking (higher-order thinking); responses are longer, calling for one- or two-sentence answers
Teacher's response	Praise correct answers; correct wrong answers; treat students' challenges to her questions as threat	Delay judgment; accept and acknowledge student contributions in a neutral rather than evaluative manner
Authority for judging answers	Teacher is authority and asserts knowledge claims that she expects students to accept without debate	Shift authority for evaluating answers from teacher to all students

Roth (1996) described a case study where the teacher's questioning was designed to "draw out" students' knowledge, and to scaffold students' discursive activity to lead to independent accounts and student-centered discussions. The students' answers were not evaluated against the external standard of canonical knowledge. Although the teacher's discourse contributions did not have an evaluative function, her authority as a teacher was undisputed. Instead, teacher authority was asserted and maintained by means other than the IRE sequence often linked to control (Lemke, 1990). By means of contingent queries, the teacher was able to ultimately lead the students to the canonical knowledge that was aligned to her lesson objectives.

Yip (2004) reported on teachers' use of questions that aimed to induce conceptual change in students studying biology. These "conceptual change" questions were aligned to a constructivist view of learning and were referred to as eliciting, challenging, extending, and application questions. They comprised those that were used to probe students' preconceptions or alternative conceptions, challenge students to resolve inconsistent views, guide students to establish relationships between existing knowledge and a new concept thereby extending their knowledge base, and help students apply a newly acquired concept to different situations.

Background to the Problem and Purpose of Study

Given the important role of discourse in meaning-making by students, there is a need to characterize the positive kinds of teacher "talk-scaffolding" in some way (Westgate & Hughes, 1997). The latter authors have suggested that a potential area for further research involves investigating the linkage between moves over stretches of discourse to find out whether some teacher moves are more enabling in evoking certain categories of student-moves, as well as to investigate the reciprocal relationship between adjacent moves. As teacher questioning is an important aspect of classroom discourse, a focus on questioning practices offers potential in enhancing our understanding of the role of teachers' questions in instructional scaffolding.

The existing literature, as reviewed above, reveals that teacher questioning practices associated with productive classroom discourse include eliciting, challenging, and extending students' ideas; use of peer assessment in evaluating students' answers; adopting the reflective toss strategy, and using wait time. Although the findings from previous studies have contributed to our understanding of what constitutes effective questioning practices, little information currently exists on how individual specific questioning strategies weave together holistically to form different approaches to questioning, or when these strategies could be used to guide students' learning of scientific content. Thus, this study was conducted to fill this gap in the research literature. The purpose of this study was to find out how and when teachers use questions in classroom discourse to scaffold students' thinking and help students construct scientific knowledge. Specifically, the study sought to develop a typology of questioning approaches used by science teachers that takes into account a variety of different strategies, and that integrates these strategies into a coherent framework.

The study was carried out in Singapore where class sizes are large and where the medium of instruction is English, although English is not the students' mother tongue. Because of large class sizes and the average middle school student's limited proficiency in spoken English, the students were generally not so forthcoming with verbalizing their ideas publicly in front of their classmates. Therefore, the teachers had to make the science curriculum accessible and mediate the conceptual information with great skill, at times adopting a language learning focus, particularly for topics that were associated with difficult scientific vocabulary.

The findings of this study have practical significance in offering teachers a variety of questioning strategies that can be used in science classes. Specific examples of their use, as described in this study, can serve to illustrate how these strategies may be adopted in the classroom. In addition, the use of some of these questioning strategies may be particularly appropriate for students learning science through English as a second language and for use with large classes, although they could also be used with native English speakers.

In a previous related study (Chin, 2006), I identified four different types of feedback associated with the follow-up move of the IRF pattern of discourse. This study extends that earlier one by showing how teacher questions in successive discourse moves build progressively on students' responses and guide students towards constructing scientific knowledge.

Methods

Setting and Participants

Six teachers teaching grade 7 science from four schools participated in the study. These teachers were selected on the basis of recommendations by other researchers who had observed their lessons earlier and who indicated that there was a fair amount of interactive questioning in their classrooms. This selection criterion was important as the focus of the study was on questioning-based practices. The average class size was 40 students per class. The students were generally motivated, on task, and ranged from average to above-average ability.

Because of large class sizes, time constraints to cover a prescribed national science curriculum, and accountability pressures on teachers for students to succeed on examinations, teaching was implemented predominantly via direct instruction or guided discussions in whole-class contexts. However, small group discussions and hands-on practical work in the science laboratory were also carried out on a regular basis. Class activities included expository lectures, whole-class guided discussions, teacher demonstrations, small-group hands-on tasks, paired discussions, and laboratory experiments carried out in pairs or individually. For activities other than expository lectures, students generally first worked on a given problem, either individually or in groups. Eventually, different groups presented their solutions to the whole class and these were compared. The teacher and students commented on the strengths and weaknesses of different approaches, with the discussion mediated through teacher questioning.

Procedure

Each of the participating teachers agreed to have an average of six of their lessons observed and either audio-taped or videotaped, or both. A total of 36 lessons were observed, with each lesson lasting an average of 1 hour. These lessons covered a range of topics included in the science syllabus. These included measurement; mass, volume, and density; elements, mixtures, and compounds; materials; photosynthesis; respiration; cells; and genetics.

Because of manpower constraints and the availability of limited audio-recorders for use in each class, only classroom discourse in whole-class settings and in some cases, small groups, were taped. The latter occurred whenever the teacher circulated among groups to talk to individual students. The audio-recorder was strapped to the teacher and so recorded whatever she said during the lessons. The video camera was set up at the back of the classroom and was directed at the teacher and students. Besides visually recording the transactions occurring in the classroom, it also helped to capture the voices of students who were seated at the back of the room. Data sources included audiofiles and videotapes of the science lessons, copies of lesson handouts given to students, samples of students' written work, and notes of meetings with the teachers. The audiofiles of recorded classroom talk were transcribed verbatim. Video-clips of the lessons were observed and interpretive notes were made.

Analysis of Data

Because the focus of the study was on teacher questioning and the lessons observed were mainly carried out in whole-class settings, with little taped data available from small-group student–student interactions, I decided to focus the analysis on teacher–student interactions. Verbal data from the transcripts were analyzed interpretively. Video-clips of the lessons, lesson handouts, and students' written work provided additional information about the classroom contexts. In particular, the video-clips provided additional information about the physical actions, gestures, and body language of participants, multimodal ways of communication, and the nature of interaction among individuals (Kress, Ogborn, Jewitt, & Tsatsarelis, 1998). For example, they captured scenes which depicted what the teacher or students wrote on the board (e.g., text, drawing, equation), the sequence in which the teacher pointed to various objects on the overhead transparencies, and students' gesticulations and behaviors (e.g., nodding of head, facial expressions). Thus, in analyzing the classroom interaction, the spoken discourse was used as one of the, but not sole, semiotic tools that participants used.

The transcripts of classroom discourse were first read through several times to get a sense of the data corpus. In deciding which utterances were to be considered as questions, I focused on those that had the grammatical form of questions and those that were posed in the form of an interrogation—these utterances sought to find out some information about students' knowledge or thinking. Some of these utterances were incomplete sentences that ended with a rising intonation, followed by a pause. They are indicated by ‘‘[. . .]?’’ in the excerpts of classroom dialogue. In the analysis of discourse, key strategic moves or questions that appeared to influence or change the direction and content of the talk were noted. Analysis focused on systematically analyzing whether any emerging patterns in the forms or functions of the discourse could be discerned, especially in association with teachers’ inputs (Westgate & Hughes, 1997), such as questions.

The discourse was analyzed based on the scientific content of the talk, type of thinking associated with students’ responses, and how the ideas evolved and progressed over time. Teachers’ questions and the corresponding students’ responses that they elicited were analyzed. I studied the relationship between the cognitive level of teacher questions and students’ responses, and noted the different ways in which teachers’ questions helped to advance students’ thinking, as manifested by their verbal responses. In particular, I examined the impact of preceding utterances on later ones, and focused on the directional flow of conceptual content embedded in the talk. By examining student utterances before and after a teacher’s question, I traced how the question influenced what students said and whether it elicited further thinking.

I identified episodes of dialogues that seemed to prompt deeper thinking or move thinking forward, and lead to productive discussions; and interpreted the questioning that occurred within these. These episodes included instances where students seemed to be engaged in active thinking and expressed thoughtful responses. I also examined how these productive responses were elicited by the teachers and the different ways in which teachers framed their questions. Tentative codes were developed by making descriptive and interpretive phrases in the margins of the transcripts, and subsequently tested in the remaining body of verbal data. These codes served as descriptive labels which represented the different ways in which teachers’ questions helped to advance students’ conceptual knowledge. These inductively derived codes were then refined through an iterative process until a useful and comprehensive scheme (see Table 2) emerged that covered the entire database (Bogdan & Biklen, 1992; Lincoln & Guba, 1985).

In working towards this schematic framework, a constant comparative method (Glaser & Strauss, 1967) was used to cluster the codes into progressively more inclusive categories forming a hierarchical taxonomy or working typologies. The emergent categories were refined by adding to, deleting from, or modifying the existing list. This resulted in a number of subcodes which were subsumed under four major codes. The subcodes depicted specific questioning strategies while the major codes characterized a more holistic questioning approach. For example, the three strategies ‘‘pumping,’’ ‘‘reflective toss,’’ and ‘‘constructive challenge’’ constitute the ‘‘Socratic questioning’’ approach. I also noted the features associated with each strategy, as well as when and how they were used.

To determine the extent to which the questioning approaches and strategies were representative of the classrooms studied, a matrix (Miles & Huberman, 1994) was drawn with the first column listing all the questioning strategies grouped under each questioning approach. The name of each teacher was then written at the top of the second and subsequent columns. Episodes of when each strategy was used were then indicated in the cells of the matrix, indexed by the specific lesson, topic, and location in the transcripts. This enabled the identification of patterns across the teachers, lessons, and topics. There were multiple instances of each of the strategies used.

In analyzing the data, I bore in mind the three dimensions suggested by Carlsen (1991) for studies on questioning: context of questions, content of questions, and responses and reactions to questions. Thus, I considered aspects of questioning related to the situational contingencies of the conversations, the development of subject matter knowledge, and the management of turn-taking.

Table 2
Teacher questioning approaches that stimulate productive thinking

Questioning-Based Approach and Strategies Used	Features	When Used
Socratic questioning	Use a series of questions to prompt and guide student thinking	To encourage student to generate ideas based on reasoning and prior knowledge
• Pumping	Encourage students to provide more information via explicit requests	To foster student talk
• Reflective toss	Pose a question in response to a prior utterance made by the student	To throw the responsibility of thinking back to the student
• Constructive challenge	Pose a question that stimulates student thinking instead of giving direct corrective feedback	To encourage student to reflect on and reconsider his answer if he gives an inappropriate response
Verbal jigsaw	Focus on the use of scientific terminology, keywords and phrases to form integrated propositional statements	For topics with several technical terms; for students weak in language skills
• Association of key words and phrases	Guide students to form a series of propositional statements to form a coherent mental framework	To introduce factual or descriptive information and to reinforce scientific vocabulary
• Verbal cloze	Pause in mid-sentence to allow students to verbally ‘‘fill-in-the-blanks’’ to complete the sentence	To elicit or emphasize keywords and phrases; for students who are not articulate or verbally expressive
Semantic tapestry	Help students weave disparate ideas together into a conceptual framework, like constructing a tapestry of ideas	To focus on ideas and abstract concepts; for topics not associated with an abundance of technical terms
• Multi-pronged questioning	Pose questions from different angles that address multiple aspects of a problem	To help students view a problem from different angles and perspectives
• Stimulating multimodal thinking	Pose questions that involve the use of a range of thinking (e.g., verbal, visual, symbolic, logical-mathematical) using talk, diagrams, visual images, symbols, formulas, and calculations	To encourage students to think in a variety of modes and understand the concept from multiple perspectives
• Focusing and zooming	Guide students to think at both the visible, macro level and at the micro or molecular level; or use questions that zoom ‘‘in and out,’’ alternating between a big, broad question and more specifically focused, subordinate questions	To help students understand a concept at both the macro, overarching level and the micro, in-depth level
Framing	Use questions to frame a problem, issue, or topic and to structure the discussion that ensues	To help students see the relationship between a question and the information that it addresses
• Question-based prelude	Use question-answer propositions; questions act as an advance organizer and lead-in to information presented subsequently	For expository talk to preface declarative statements and to focus student thinking
• Question-based outline	Present a big, broad question and subordinate or related questions visually (e.g., on slides)	To visually focus students' thinking and help students see the links between the big question and subordinate questions
• Question-based summary	Give an overall summary in a question-and-answer format to consolidate the key points	At end of lesson to recapitulate key concepts succinctly

Results

Using Questions to Frame Classroom Interaction and Scaffold Students' Thinking

An analysis of classroom talk and interaction revealed four different productive questioning approaches adopted by the teachers: Socratic questioning, verbal jigsaw, semantic tapestry, and framing. Table 2 summarizes these various approaches, their features, and the conditions under which they were used. In the examples that follow, [. . .] denotes a brief pause, three dots ''. . .'' indicates the omission of irrelevant words from within a sentence, while four dots ''. . ..'' means the omission of irrelevant words from one or more sentences. Specific identifiable speakers are represented by their initials, while unidentifiable voices from among the students are denoted by ''S'' (individual voice) or ''Ss'' (multiple voices).

Socratic Questioning

In Socratic questioning (e.g., DePierro & Garafalo, 2003; Holme, 1992), the teacher used a series of questions to prompt and guide students' thinking, instead of telling the students a mass of information via direct instruction. The questions functioned in probing, extending, and elaborating on students' ideas, thereby extracting the information from ''within'' the students. Features of this questioning approach include the use of pumping, reflective toss, and constructive challenge.

Pumping. This refers to the teacher pumping the student for more information during the question-answering process and putting the onus on the student to provide more information (Hogan & Pressley, 1997). The primary goal of this strategy was to encourage students to further articulate their thoughts and ideas. The pumps comprised mainly explicit requests for more information (e.g., ''What else?''), the use of positive feedback (e.g., ''Yeah'', ''Correct'', nodding of head) and neutral feedback (e.g., ''Okay,'' ''Uh-huh,'' ''Mm-hmm'').

In a lesson on the physical characteristics of different materials, teacher G posed a problem to the class of how Abdullah, an Olympic athlete who had won a gold medal, wanted to find out whether his medal was made of pure gold. The students first discussed their solution in small groups and a whole-class discussion then ensued.

T: Marissa, tell us what we need to do.. . . *How is Abdullah going to solve the problem?*
M: Find the density of the gold.
T: Find the density of gold. *In order to find the density of gold, what must we do?*
M: Find the mass.
T: We need to find the mass first. *How to find the mass?*
M: [Use] the weighing machine. . . an electronic balance.
T: By using an electronic balance. . .. *What do you need to do next?* . . . Dania?. . ..
D: Find the volume.
T: You need to find the volume, and *how do you find the volume?*
D: Use a displacement can. . ..
T: So now, you've got the mass obtained from the beam balance or electronic balance. You've got the volume obtained from the displacement method. *With these two values, how do we find the density?*. . .Xiyun?
X: Mass divided by volume.
T: Mass divided by volume. OK, so we've got the density of the medal. *What do we do next?* Adellah? . . ..

A: Compare with the density of real gold. . ..
T: Right, compare with the density of the real gold. There are references that show you what is the density of real gold. Check with your calculation. If it's the same, it means what? The medal is made of solid gold. If not, it would be either impure gold or it could be another metal colored in gold.

From the above excerpt, we see that the teacher typically restated the students' answers, and then followed up by posing another question that led to the next step of the thinking process. Finally, the content pursued by the teacher's probing questions was summarized by the teacher and consolidated in a "mini-lecture."

Reflective Toss. van Zee and Minstrell (1997b) described a "reflective toss" as a question that is posed by a teacher when she wanted to throw the responsibility of thinking back to the student in response to a prior utterance made by the student, which may be a question or a statement, thereby shifting toward more reflective discourse. The following is an example.

In a lesson on photosynthesis, teacher R was discussing the activity on testing a green leaf for the presence of starch. When discussing the procedure involved, the students noted that the leaf had to be immersed into a boiling tube half-filled with alcohol until it lost its color.

S1: How to remove the chlorophyll from the alcohol?. . ..
T: Then you have to do extraction. . .. *How are you going to remove the alcohol from the green solution?* Very good question asked. *Can you recall your separating techniques? What will you use? Any suggestions to his answer?*
S2: Distillation
T: Yes. Correct. You can do distillation. . . That is, you heat it [the green solution] to a certain temperature that is around 80 degrees Celsius. *What happens?*
S2: Vapor is formed.
T: The vapor comes out. *And what is left inside the container?*
S3: Green colour.
T: Green pigment. Alright?

When student 1 enquired how to remove the chlorophyll from the alcohol, teacher R redirected the question to the class instead of giving a direct answer herself—this move elicited further generative thinking in her students.

Constructive Challenge. Sometimes, the teachers used the strategy of "constructive challenge" instead of direct corrective feedback when students gave inappropriate answers. They posed a question that challenged students' thinking and prompted the students to reflect on and reconsider their answers. In the following example, teacher L was discussing the procedure involved in determining the volume of a small wooden block that floats, before carrying out the practical activity. She invited the students to brainstorm ideas and compared three different methods proposed by the students. As the students spoke, teacher L used the board to draw labeled diagrams that corresponded to the students' descriptions.

A student suggested using a measuring cylinder and filling it with water. He proposed taking three measurements by first measuring the volume of water only, and then measuring the volume again with a stone immersed in it. After removing the stone from the water and then using a string to tie the wooden block to it, both the stone and wood would be submerged into the water, with the stone acting as a sinker (Method 1). The measurements to be taken would be V1 (volume of water), V2 (volume of water + stone), and V3 (volume of water + stone + wood). To find the volume of the wood, one would subtract V2 from V3 (i.e., V3−V2). Teacher L then asked the class whether it was actually necessary to find the volume of the water only and questioned, "*Where does V1 come into the calculation?*," "*Was it necessary for you to find the volume of water?. . .. Could you have done with lesser [fewer] steps?*" and "*Can you modify it in such a way that you do not need to do unnecessary steps?*."

Huiyi then suggested Method 2, where she would omit the step that involved finding the volume of the stone. She proposed first finding the volume of both the water and stone (V1), removing the stone, and then measuring the volume of water, stone, and wood, with the latter two objects tied together (V2). To find the volume of the wood, she would then calculate "V2−V1". After emphasizing that it was not necessary to find the volume of the stone, teacher L then asked what might be some factors affecting the accuracy of the measured volumes. She posed questions such as "*What do you think are some of the problems and how do you think you can overcome it?*" and "*How would that affect the accuracy?*." Marcus replied that "some of the water might be removed together with the stone" and "the water level will be reduced." Teacher L then posed a question "*How would you avoid removing the water?*" and gave students time to discuss their ideas in small groups.

After a brief small-group discussion, teacher L called on Jonathan to suggest an alternative method (Method 3). Jonathan went up to the board, and drew a stone and a block of wood connected by a string. He said to first submerge the stone only into the measuring cylinder filled with water, with the wooden block being lifted out of the water. After that, he would submerge both the stone and wood. Doing this would minimize the amount of water lost. Method 3 was thus a further fine-tuned version where one could avoid having to put in and take out the stone unnecessarily.

The students applauded Jonathan's effort. Teacher L then reiterated that Method 3 would help to reduce the error involved since it would not involve the unnecessary loss of water. By challenging students to propose and evaluate their own alternative ideas, teacher L guided them to improve on their solutions to the problem.

Verbal Jigsaw

This approach to questioning was characterized by a focus on the use of scientific terminology, as well as the association of key words and phrases. It was used by the teachers when they wanted to introduce factual or descriptive information, to reinforce scientific vocabulary particularly when the topic was associated with a number of technical terms, to foster understanding of a sequence of steps, and to elicit convergent answers. The teachers' questions served to elicit the appropriate and essential words from students for the construction of declarative knowledge in the form of a network of related concepts. They guided students to piece together a series of propositional statements that were integrated to form a coherent mental framework and to build a relational understanding among the different concepts addressed.

By combining disparate ideas from different individuals, this approach is akin to piecing together or arranging the component pieces of a "verbal jigsaw" to form a composite picture of the topic. Because of the focus on the appropriate language and the mastery of key phrases, this approach seemed particularly suitable for students who were weak in language skills and who had difficulty in expressing or elaborating on their own ideas. When adopting this approach to questioning, the teachers sometimes used the strategy of a "verbal cloze" where they paused in mid-sentence to allow students to verbally "fill-in-the-blanks" to complete the sentence. An example is "*Now, what do you notice about these chromosomes? They are being [. . .]?*". Another strategy, association of key words and phrases, is described below.

Association of Key Words and Phrases. As an introduction to the topic of mitosis in a unit on cells, teacher S distributed a handout which consisted of a number of diagrams (Figure 1) that showed the various stages of mitosis in a jumbled up sequence. She then told the students to work in pairs to rearrange the diagrams so as to correctly represent the sequence of steps involved, starting with a parent cell and ending with two daughter cells. The diagrams, which were labeled from a to f and which were not accompanied by any text description, showed the following: (a) chromosomes separated and moving towards the poles (representing anaphase), (b) parent cell with four chromosomes, (c) chromatin condensing into chromosomes which consist of two sister chromatids (representing prophase), (d) chromosomes aligning at the middle of the cell, with nuclear membrane broken down (representing metaphase), (e) two daughter cells, each with one nucleus (representing cytokinesis), and (f) daughter chromosomes arriving at the poles, cell membrane pinching in, and cytoplasm dividing (representing telophase).

After the students had completed the task in pairs, teacher S used a transparency to guide a whole-class discussion. She asked, "OK, *what's the first one? First step?*" The students responded that the sequence would be "b, c, d, a, f, e." The following conversation then ensued.

T: *Would anyone like to try to explain how you figured that out?*. . .. B is a parent cell, right? (pointing to b). *C, now why do you all decide that c should be the next step?*. . .. *What is the difference between b and c?*
S: It [chromosome] has got "two legs," split halfway (referring to sister chromatids).
T: Split halfway. . . *What is each one of these?*
S: Chromosomes.
T: *What do these uh, ball and stick figures represent?* Sarada, what do they represent?. . ..
S: Chromosomes.
T: Chromosomes, OK, *how many chromosomes are there in this parent cell?* (pointing to b)
Ss: Four.
T: Four, OK. . .. *Now, what do you notice about these four chromosomes? They are being [. . .]?*
S: Paired.
T: Paired up. They are being paired up, OK. *According to what?*
Ss: Size.
T: OK, according to the size.

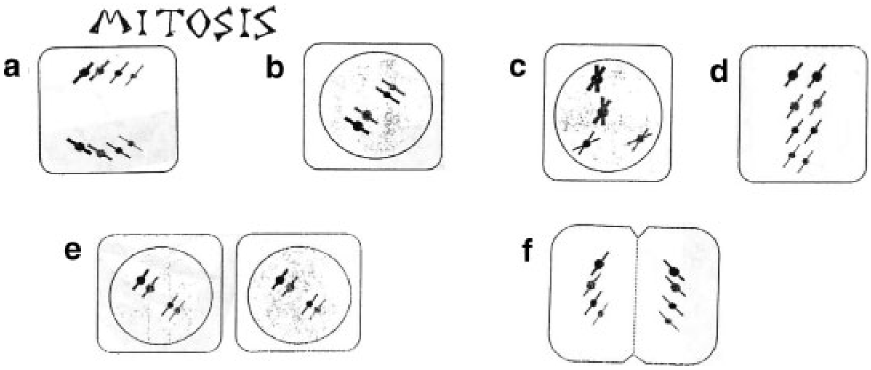

Figure 1. Diagram showing mitosis on the handout given to students.

Teacher S then pointed out that from the stick-like structure in stage b, the chromosome then assumed the shape of a cross or an ‘‘X’’ in stage c. She also noted that the chromosomes doubled in number, from four chromosomes in stage b to eight in stage c, and so the daughter cells would ultimately ‘‘end up with the same number of chromosomes as the parent cells.’’ After further pointing out that the chromosomes were aligned at the center of the cell (in stage d on the transparency) but towards the edge of the cell in stage a, she then pointed from stage a to f and asked, ‘‘*What’s the difference between these two drawings?*.’’ A student replied that the cell was ‘‘bulging,’’ and that it was ‘‘dividing.’’

T: Yeah, the cells are dividing. You see this bulge, uh, this umm, cleft here (in figure f). And then *you see this dotted line here, signaling the formation of what?*

Ss: Formation of another cell. . .. Formation of a cell.

T: *Formation of which structure of the cell?*

Ss: The membrane.

T: Cell membrane. . . *And from this step to this step, what is the difference?* (pointing from stages c to d). . .. Zeny, what’s the difference?. . ..

Z: It gets smaller. . ..

Ss: (clash of voices) No!. . .. They are no longer in this circle thing. . ..

T: *What is this circle thing?*

Ss: Nucleus.

T: . . .. This whole circle represents the nucleus. So . . .before the chromosomes actually divide, you have the nuclear membrane being disintegrated. . .. The nuclear membrane actually breaks down.

After going through these essential concepts with the students, teacher S then emphasized the relevant scientific vocabulary associated with these ideas. She used a transparency with text situated next to each of the diagrams, told students to identify the keywords on the transparency, highlighted them by underlining them, and told them to take notes next to the diagrams.

T: Some of the keywords. Now, for this block [of text] here (pointing to stage c), what. . .what are the key words? *Can you identify some of the key words here?*

S: Replication.

T: Replication, yes. . . Replication, which means making many copies. . . What is the verb?

S: Replicate.

T: Replicate. Good (writing the word ‘‘replicate’’ onto the transparency). *And then, what about this one (pointing to stage d)? What are some of the keywords?*

S: Nuclear membrane breaks down.

T: Nuclear membrane breaks down, OK. And the chromosomes actually move to opposite ends of the cell. . .. *Now, and this one here? What’s the key word?* (pointing to stage f)

S: Constrict.

T: Constrict, OK. *And this one, what’s the key word* (pointing to stage e)?

Ss: Form. Reforms.

T: Reforms. The nuclear membrane reforms. *What is something that’s very important here?*

S: Exactly the same type of chromosomes.

T: Exactly the same number and type of chromosomes.. . . *So, to summarize, for mitosis, from one parent cell, you get how many daughter cells?*

Ss: Two.

T: Two daughter cells.

By asking students questions to identify and articulate the key words and phrases associated with each stage of mitosis (e.g., ‘‘replication’’ in stage c, ‘‘nuclear membrane breaks down’’ in stage d, ‘‘constrict’’ in stage f, as well as ‘‘nuclear membrane reforms’’ and ‘‘exactly the same number and type of chromosomes’’ in stage e), teacher S recapitulated the key ideas of the topic. It also seemed to be an effective way of helping students to master the salient concepts and important scientific vocabulary (e.g., replication, daughter cells) in a systematic manner, especially for students who were weak in language skills. Teacher S emphasized the appropriate use of language such as ‘‘chromosome,’’ ‘‘cell membrane,’’ and the use of the term ‘‘nucleus’’ instead of the ‘‘circle thing’’ as described by a student.

Semantic Tapestry

The focus of semantic tapestry was on the holistic integration of concepts. The metaphor of a ‘‘semantic tapestry’’ suggests that teachers used this questioning approach to help students meaningfully weave together their disparate ideas into a coherent mental framework of related concepts. The focus was on building conceptual and relational understanding in students, much like constructing a tapestry of ideas. Unlike the verbal jigsaw described above, it lends itself well to topics that are not associated with an abundance of technical terms. Features of this questioning approach include multi-pronged questioning, stimulating students’ use of multimodal thinking, as well as focusing and zooming.

Multi-Pronged Questioning. By using multi-pronged questioning, the teacher posed questions from different angles that addressed the multiple aspects of a problem. In having to respond to the teacher’s questions, students were stimulated to think more deeply about a given topic or issue and to view the topic from different perspectives.

The lesson described below involved the use of a given dichotomous key to classify a number of leaves with fictitious names. Teacher S addressed this topic by questioning in a variety of ways. First, she gave students a textual description of a leaf and told them to use the dichotomous key to identify the name of the leaf. Second, she gave students a drawing of an unnamed leaf, told them to describe it in their own words, and then to identify it. Third, she gave students the name of a leaf, required them to describe it in their own words, and then to imagine and draw the leaf.

T: So, let’s look at the first question here. . .. OK, question 1A. *What name is given to each of the plants described below?* Plant 1 has a long, thin, hairy leaf, with parallel veins, and a pointed tip. . .. *So what is the very first question that you’d go to?*
S: Are the leaves long and thin.
T: OK, are the leaves long and thin. . . So the response is a [. . .]?
Ss: Yes.
T: Response is a yes, so you go to question 2. *Do the leaves have parallel veins?*
Ss: Yes.
T: Yes, OK, so you go to 3. *Does the leaf have a pointed tip?*
Ss: Yes.
T: Yes again. [Go to] 8. *Does the leaf have hairs?*
Ss: Yes.
T: Yes. So it’s a. . .
Ss: GRIN.
T: Grin, G-R-I-N, OK? Who got that right? OK, very good.

Teacher S then proceeded to part 2 of the worksheet where students were given drawings of leaves.

T: Right, 2A, what is the name of each of these plants?. . .. You're given a drawing with no word description of umm, no verbal description of the characteristics. . .. *What's the name of this plant?* Teck Soon?

TS: PLIM

T: Plim. P-L-I-M. Good. *How do you describe this leaf?*

The student then responded with the descriptions ''long and thin,'' ''parallel veins,'' ''non-pointed,'' and ''non-hairy.''

T: Non-hairy, OK, by the way, *how do you tell that it's hairy or non-hairy?*

Ss: See dots on the drawing.

T: You see the dots on the drawing, OK, good. . .. Any questions?. . .. OK, let's move on to [question] 3. Draw a diagram of a leaf.

Teacher S then asked the students how they would tackle Question 3 where they were required to draw the leaf, given its name. The students replied that they would ''work backwards.'' Teacher S then affirmed their answer by saying that they would ''backtrack'' by looking at the ''final identity'' of the leaf, listing all its characteristics, and then drawing the leaf. The teacher then called a student to the board to draw how he thought the leaf would look like. She then referred to his drawing and continued as follows:

T: OK, this one, JANG [leaf], how would you describe JANG?

S: Hairy. . .. Network veins. . .. Long and broad.

T: Broad and it has a pointed tip, OK, pointed tip. So he has drawn all the characteristics in this diagram. Very good, OK.

At the end of the lesson, teacher S set the students a task for homework where they had to work in groups to construct a couplet kind of dichotomous key to identify each student from one of two given groups in the class, using descriptions based on their physical characteristics.

We see from the above excerpt that teacher S posed her questions from various stances, addressing the use of the dichotomous key in three different ways, which required students to identify a leaf from either a text description or drawing, to verbally describe, and also to draw the given leaves. In responding to the questions, the students had to translate information between written, verbal, and visual forms of representation. At the beginning (for question 1A), teacher S prompted students with more specific questions pertaining to physical features such as the shape, venation pattern, type of leaf tip, and the presence or absence of hairs. This required students to use process skills such as observing, comparing, analyzing, and inferring. Subsequently, the teacher's questions became more open-ended for question 2A (e.g., ''How do you describe this leaf?'') as the students became more familiar with the use of the dichotomous key. Such questions required students to be more generative in their thinking. Students also had to communicate their understanding not only verbally but also in diagrammatic form. Finally, students had to apply their understanding of a dichotomous key in a different context when they had to construct one for homework.

Stimulating Multimodal Thinking. To encourage students to think in a variety of modes, the teacher posed questions that prompted students to articulate their ideas in the form of verbal or written text (verbal thinking), conjure up mental images forming a ''visual collage'' (visual thinking), or think by using symbols (symbolic thinking).

In a lesson on mass and density, teacher L compared the density of ice with water. She used a number of probing and prompting questions to elicit multimodal thinking in students. These questions tapped into linguistic, visual, and symbolic resources that made use of talk, diagrams, visual images, symbols, formulas, and calculations. This involved students' use of verbal, visual, and logical-mathematical thinking. By posing questions that required students to switch between various modes of thinking, teacher L helped students to understand the concept of density from multiple perspectives.

T: *If ice floats on water, as we always notice, what does it tell you about the density of ice?* Peiji?
P: Ice is less dense.
T: The ice is less dense than water. . .. *Why is ice less dense than water? When ice freezes, what actually happens? . . ..*
S: It expands.
T: It expands. *And when it expands, what happens to the volume of ice?*
S: Larger volume. . ..
T: OK, ice. When you have water and then you freeze it (drawing an ice-cube tray on the board with ice cubes inside bulging out). . .. Let's say, an ice tray, like this, and you fill it to full. If you put it [water] to the brim, . . . what happens after the water freezes? Do you still see like that? *Sink in or bulges out?*
Ss: Bulges out.
T: Bulges out. What has happened is that the water. . . when it freezes, it expands, right? *And in expansion, which quantity changes?. . .. The volume increases or decreases?*
Ss: Increases.
T: The volume increases. OK. *Which quantity doesn't change?*
S: Mass.
T: The mass doesn't change. Mass remains constant. If mass is constant, and if you are calculating density, *what would happen to the density as the same mass of water changes into ice?* Density equals mass divided by volume (writing the equation $d = m/v$ on the board).

The teacher then substituted hypothetical values of 5 g for the mass, and compared the values for the density obtained with volumes of 5 and 6 cm^3.

T: *So what has happened to the density? The density is now more or less?*
S: Less
T: Less. It's now zero point. . . *what's the value?* [0.83 g/cm^3] It is no more 1 g/cm^3.

In the excerpt above, we see that the teacher first discussed the freezing of ice at the macroscopic level by invoking students' daily life experiences. She mentioned that ice floats on water and also asked students what happens to ice in the ice-tray when water freezes. Then she brought the concept to a quantitative and symbolic level by referring to the use of the density formula where she substituted hypothetical values for the mass and volume. In this way, students could see that the numerical value for the density of ice was lower than that of water. In the following excerpt, teacher L continued by tapping into students' visual thinking where students could use their "mind's eye" to evoke mental images.

T: *When the volume of this same mass increases. . . what happens to the molecular packing? Are the molecules still as close as before?*
Ss: No.
T: *More spaced out? Closer? The molecules are now more [. . .]?*
S: Spaced out.

T: Spaced out. [The] intermolecular distance increases.... *And when the intermolecular distance increases, what would happen to the number of molecules that it can pack into the same unit volume? Can you pack in more molecules or less [fewer] molecules now if the intermolecular distance increases?....*

Ss: Less.

T: There will be less [fewer] molecules per unit volume. *What will happen therefore to the mass per unit volume? Increase or decease?* [...]

S: Decrease.

T: If you have less [fewer] molecules packed into the same unit volume, there will now be a decrease in the mass. Less mass per unit volume, and therefore there is a decrease in density (drawing diagrams of molecules on the board).... Therefore, the density of the ice is less than the density of the water.

By referring to the intermolecular distance, teacher L helped students to paint a picture of how the packing of the molecules is related to the mass, volume, and density of ice. As a closure to the lesson, teacher L reiterated that one could understand this by either ‘‘seeing in terms of calculations’’ or ‘‘in terms of molecular packing.’’ By asking questions that were related to verbal, visual, and symbolic representations, she addressed the relevant concepts via talk, diagrams, images, and a mathematical formula.

Focusing and Zooming. In focusing and zooming, the teacher used her ‘‘questioning lens’’ to adjust the nature of her questions, depending on the kind of thinking she wanted to elicit. Focusing and zooming could refer to instances where students were guided to think at both the visible, macro level and at the micro or molecular level.

For example, in the series of verbal exchanges given above on the density of ice, teacher L also used the questioning strategy of focusing and zooming. Beginning with questions that targeted thinking at the macro level (‘‘When ice freezes, what actually happens?’’ and ‘‘If you put it [water] to the brim...what happens after the water freezes?’’), she stimulated students to apply their prior knowledge at the observational level to respond with ‘‘it expands’’ and ‘‘bulges out.’’ Subsequently, when referring to the numerical values substituted into the density formula, her questions (‘‘So what has happened to the density? The density is now more or less?’’) encouraged students to analyze the numerical relationships among density, mass, and volume, and to infer that the density would be ‘‘less.’’ Finally, teacher L’s questions zoomed in to focus on the submicroscopic or molecular level when she asked: ‘‘And when the intermolecular distance increases, what would happen to the number of molecules that it can pack into the same unit volume?’’

Focusing and zooming also refers to responsive questioning where the teacher adjusted her questions to students’ responses, with each subsequent question building on to the previous one(s) to help students progressively construct an integrated framework of ideas. The questions progressively zoomed ‘‘in and out,’’ alternating between a big, broad question to more specifically focused, subordinate questions. These questions were designed to elicit, probe, extend, and elaborate on students’ thinking, with a view to helping students construct conceptual and procedural knowledge. Such questions tapped into students’ prior knowledge as well as their use of various process skills such as observing, comparing, hypothesizing, predicting, measuring, explaining, analyzing, inferring, evaluating, and formulating conclusions.

In a lesson on designing and performing an investigation to find out the effect of surface area of a solute (viz., coarse vs. fine sugar) on the rate of dissolving, teacher R used a number of overarching questions to introduce each stage of the investigation, and this was followed by a number of further questions which ‘‘zoomed in’’ specifically on the different aspects of each stage. For example, at the beginning, teacher R first focused on getting students to hypothesize and predict by posing questions such as ‘‘*If you cut them [sugar cubes] into several pieces, the surface area exposed to the surrounding increases or decreases?*’’ and ‘‘*Therefore what happens to the rate of dissolving?*’’ Subsequently, she ‘‘zoomed out’’ to the next stage where she guided students to identify the materials needed for the investigation by posing a broad question such as ‘‘*What materials would you like to use?*’’ Under this overarching question, she then zoomed into the details using questions such as ‘‘*What else?*’’ and ‘‘*What other apparatus would you want to use?*’’

By a similar process of focusing and zooming, she guided students through the investigation which involved the identification of variables (e.g., ‘‘*What are the variables to be investigated?*,’’ ‘‘*What variables should be varied or kept constant?*’’) and carrying out the steps of the procedure (e.g., ‘‘*How should we start?*’’, ‘‘*Measure how much [water]?*,’’ ‘‘*How much [sugar] do you suggest we add?*’’). Other questions that teacher R asked pertained to the recording of results (e.g., ‘‘*How would you put [display] your table?*,’’ ‘‘*What is the unit [of measurement]?*,’’ ‘‘*How many decimal places [do] you put for your stopwatch?*’’), interpretation of findings (e.g., ‘‘*What do you infer from the observation?*’’), making of conclusions (e.g., ‘‘*So what can you say about [the] conclusion?*’’), and application to everyday life (e.g. ‘‘*Can you see the link between this experiment and your daily life?*,’’ ‘‘*What’s the rationale behind using fine salt [when you cook]?*’’ There seemed to be a rhythm in the teacher-led discussion, where teacher R adjusted her questioning lens to periodically focus on a particular stage and zoom in or out, as appropriate.

The strategies of multi-pronged questioning, stimulating students’ use of multimodal thinking, as well as focusing and zooming encourage an agility of the mind, thereby fostering students’ ability to view a problem from different angles, across different modes, and from both macro and micro perspectives. This has the potential of enhancing a student’s mastery of the relevant concepts, thus leading to a deeper understanding of the subject matter.

Framing

Framing refers to an approach where questions were explicitly used to frame a problem, issue, or topic and to structure the discussion that ensued. Three teaching strategies associated with this approach are referred to as question-based prelude, question-based outlines, and question-based summary. While the teacher tended to answer her own questions in question-based prelude and summary, she expected students to respond to her questions in question-based outline. This was the main difference between these three framing strategies.

Question-Based Prelude. Question-based prelude was characterized by a number of question-answer propositions in expository talk. The teacher embedded focus questions in her lecture presentation to introduce new information instead of just plain teacher-telling. These questions were used as a preface to present small chunks of information which comprised mainly declarative statements. Thus, they not only acted as an advance organizer but also made the teacher’s thinking visible, and served to model the act of question generation for each conceptual aspect of a lecture. In addition, interspersing such questions in between declarative statements could have helped students to mentally prepare and better focus on the content that was yet to come, and to know what question it was that the subsequent information was going to address.

Question-Based Outlines. For this strategy, the teacher used a big, broad question to introduce the topic or problem and define its macrostructure. This was then progressively followed by sub-questions which pertained to the different subordinate concepts or different aspects of the problem. The questions were presented visually either on a Powerpoint slide, transparency, or handout, and gradually tapered to address the finer details of the topic in hand. The physical presence of the questions provided a public object for students to focus on and refer to during the lesson, making them the objects of inquiry.

For example, in an introductory lesson on respiration, teacher R set the students a few problems or ''thinking tasks'' for them to work on. Students first discussed in groups and then presented their answers to the class. Each problem was written in the form of an overarching trigger question as the title of the task, followed by a series of sub-questions which guided students to address various aspects of the main question. The questions were shown on PowerPoint slides and also on handouts which were distributed to students.

An example of a given task was: Imagine you are an oxygen particle. Trace the path taken by the oxygen particle beginning from the nose to the cell. The sub-questions that followed included (a) What happens to the oxygen particle in the alveolus? (b) What would be the final destination of the oxygen particle?, (c) What happens in the cell? (d) What is the chemical process that occurs here? (e) What is the purpose of this chemical reaction?

To help the student presenter trace the journey of the oxygen particle, teacher R showed a number of slides as the student spoke. These slides included diagrams of the respiratory system, a lung showing the alveoli, and a cell. The following exchange occurred.

T: Imagine you're an oxygen atom. You start moving, going through the nose. *What is the first path taken?.*.. *Where does it go first?*
S1: When oxygen enters the nose, it goes through our nasal cavity. Then it will go down to the wind pipe and reach the lungs (pointing to the windpipe on the diagram and tracing the path with his fingers).
T: *What is the name of the windpipe here? You have a special name called [...]?*
S1: Trachea
T: Trachea.... *Next, where does it go?*
S1: Then it will go to the left and right bronchus....
T: Next, *what happens then?*
S1: It goes into smaller [...] It goes into smaller bronchioles.
T: Yeah. It branches into bronchioles. *And finally where do they go?*
S1: Finally, finally it will go to the [...] It will go to another smaller part, and then it will be [...] this will be the lungs, and it will be [...] air sac.
T: Yes, air sacs. Plural, alveoli. One alveolus, many alveoli. Be careful with singular and plural. Once it goes into the air sacs, what's the next part? (referring to diagram on slide)....*Where would it go from here?*
S1: Go, dissolve into the blood stream.
T: Dissolve? Are you able to dissolve?....You don't dissolve, alright? You...diffuse through. *Then what do you get attached to in this blood vessel?*
S1: It will attach to red blood cell and then it will be carried to the heart.
T: Go to the heart. *After the heart, where will you go?*
S1: Then it will go to the other parts of the body....
T: *Which part of the body?*
S1: The cell.
T: OK, you go to the cell. That's right....*Which part of the cell do you think the oxygen atom will go to?*
S1: It will pass through the membrane.
T: It will pass through the membrane. Correct. Where *would it go to?*
S1: It will go to the mitochondria where it will be used to burn [...] produce energy and water and carbon dioxide as a by-product.

T: Yeah. *And what do you think is the name of the process?*
S1: Respiration
T: Yes. Respiration. . .. It [mitochondrion] is like a power house. And these are the reactions that occur. You find that glucose, together with oxygen, will be broken down to produce energy, carbon dioxide, and water. *Can you tell me what is the purpose of the energy released?*. . .. Everyone, put on your thinking cap. *What is the purpose of the energy released?*
S1: To do work.
T: Yeah. *Other than that? Anyone knows?*
S2: To move.
T: Yes, correct. . .. *Any other things?*
S3: It will allow itself to reproduce. . .. For cell division.

Because the students had to find out the answers to the given questions themselves and then give a presentation in front of their classmates, it was actually the student presenters rather than the teacher who provided the class with the requisite information. The questions served to scaffold students' thinking and guided them in their search for information about the topic in hand. The teacher acted as a facilitator, using questions to prompt and probe students to give details, wherever necessary.

Another teacher (teacher L) also used outline questions and presented them on a PowerPoint slide to focus student's thinking as she spoke. However, unlike the example above which focused on factual, descriptive information and sequential thinking, some of her questions were deliberately framed to provoke cognitive conflict and to stimulate students to think at the explanatory level and to propose mini-theories. While discussing the big question on what density meant, teacher L showed questions such as "*Which is heavier? Iron or wood?*," "*Is an iron nail heavier than a wooden table?*," "*What is wrong with this way of comparison?*," "*How should we compare?*," "*How do we standardize?*," "*Do we compare equal size, equal shape or equal volume?*," "*Why does the same volume of iron and wood have different mass?*," and "*What gives rise to the difference in their density?*" The questions were presented one at a time, together with a number of diagrams or pictures, as each idea gradually unfolded during class talk.

Other outline questions presented on the slides included "*The molecular mass of alcohol is larger than that of water but why is alcohol less dense than water?*," "*Does wood have a larger density when it is in the form of a table, chair, or just a wooden stick?*," and "*Does copper coil, copper rod, and a copper cylinder have the same density?*"

By using question-based outlines to focus and structure classroom discussions, the teacher prompted students to consider each important concept in some depth.

Question-Based Summary. In question-based summary, the teacher gave an overall summary of the lesson in a question-and-answer format to consolidate the key points. The following excerpt was from the end of the lesson on respiration described above, where teacher R recapitulated the key concepts of the topic by using a question to frame a given concept and then answer the question herself.

T: *What did we learn today?* Everybody, look up. . .. You need to know two adaptations of alveoli for gaseous exchange. Remember the air sacs?.. . . It [they] must have a large surface area for the exchange of gases. *How to have large surface area?* A large network of blood capillaries. And second point, it has to be very thin. *How thin?* One cell thick, for easy exchange of gases. Then we were also talking about pathways for gases. [For the] oxygen particle, it must pass through your nose. *And then what?*

> Trachea, bronchus. One bronchus, many bronchi....Then it branches into the bronchioles. *And finally, the air goes where?* Alveoli. In the alveoli, exchange of gases takes place. Next, we also talked about respiration. *Aerobic cellular respiration is actually the chemical process of breaking down what? Breaking down glucose and oxygen into what?* Carbon dioxide, water, and energy. *Where does it occur?* In the powerhouse of your cell. *What is the powerhouse of your cell called?*
>
> S: Mitochondria

By prefacing her expository summary with leading questions, the teacher could have helped students to focus their thinking and anticipate the answers.

A variation of the question-based summary was observed in other lessons where teachers asked questions in an IRE format and elicited responses from students instead of articulating the answers herself. Although such questioning exchanges may appear unremarkable and be interpreted by critics as characteristic of rote-learning, they can, if used appropriately and occasionally, serve a useful function in reinforcing basic information which students are expected to remember and master, especially for topics where there is much factual information to recall. After all, it is only when one has attained a firm grasp of the basic fundamentals of a topic that one can proceed to apply this information to solve more difficult problems pitched at a higher cognitive level.

Discussion

In this study, I analyzed the anatomy of classroom talk and interactions across classrooms taught by different teachers. The objective was to characterize the underlying structure of talk and, in particular, the questioning approaches adopted by teachers that encouraged productive thinking in students. Concrete examples of ways of questioning that helped teachers make their classroom discourse more thought-provoking were provided. Where appropriate, metaphors were used as part of a working vocabulary to represent these ways of questioning.

Implications for Instruction

When using Socratic questioning, the teacher acted as an interlocutor and a coach who provided scaffolding through asking guiding questions to advance students' thinking. In using verbal jigsaw, the teacher directed students to attain a grasp of the essential working vocabulary that is necessary to express their ideas in a scientific way. The use of verbal cloze also lessened the linguistic load of students with weak language skills. As for the semantic tapestry approach, the use of multi-pronged questioning and stimulating multimodal thinking could have tapped into students' multiple intelligences (Gardner, 1993, 1999) that involve the use of verbal, visual, logical-mathematical, and other modes of thinking, thereby allowing students with different learning styles to think in ways that are best aligned to their natural dispositions.

In using framing as a questioning approach, teachers used questions to preface, structure, or summarize each small chunk of information addressed. As knowledge consists of question-answer propositions (Dillon, 1988a, p. 21), these strategies can help students to see the connection between what they are learning and the question that the information is addressing. This makes learning more meaningful because the questions make explicit, the "what-why-when-which-how" relationships among the concepts addressed. Also, in the case of question-based outlines, the specific, subordinate questions nested within a more general overarching question can serve to move students' thinking forward in small incremental steps towards the teacher's final goal. Thus, in planning a lesson that makes use of the framing approach, the teacher could first identify and sequence a set of questions that the lesson will answer. As a result, the lesson will consist of an ordered set of systematically interrelated question-answer propositions.

A common thread running through all these approaches is that teacher questioning was very purposeful in that the teacher followed up on a preceding student contribution in a productive way. The questions were built around various forms of thinking. Some were aimed at recall of information, whereas others were process-oriented, stimulating students to generate ideas, apply concepts, make comparisons, formulate hypotheses, predict outcomes, give explanations, analyze data, make inferences, evaluate information, and make connections between ideas. The questions served as the rungs of a ‘‘cognitive ladder’’ enabling students to gradually ascend to higher levels of knowledge and understanding. They elicited responses from different individuals that progressively added more information to existing ones and that contributed to a growing framework of ideas. By using students’ responses as a platform for further inquiry and a series of questioning moves to lead students towards target conceptions, the teacher helped to bridge the cognitive gap between the questions asked and the knowledge base of the students. Thus, conceptual knowledge was socially co-constructed as new ideas emerged from the blending of voices and gradually meshed to produce a dialogic outcome.

Another common feature observed among the teachers’ questioning approaches was that the teachers often reiterated students’ responses following their questions. This phenomenon, termed ‘‘revoicing’’ by Chapin, O’Connor, and Anderson (2003), served not only to affirm students’ responses but also to make their ideas available to all in the class, thereby making it ‘‘common knowledge’’ (Edwards & Mercer, 1987).

The findings of this study showed discourse patterns other than the traditional IRE sequences. Although the teachers still maintained their position of authority and control in the classroom by orchestrating the whole-class discourse, their talk was not limited to merely ‘‘teaching by telling’’ or ‘‘questioning to evaluate.’’ Some questioning sequences had the quality of exploratory and facilitative rather than evaluative talk. In such discursive episodes, teachers employed questioning approaches that were designed to elicit students’ ideas, scaffold student thinking, prompt students to think aloud and verbalize their ideas, and nudge students toward conceptual development instead of just assessing the correctness of their responses. These questions were employed to coach students along guided paths towards the construction of canonical science knowledge. Thus, they acted as psychological tools used by teachers in the social construction of knowledge. As Edwards and Mercer (1987) pointed out, a basic ‘‘power asymmetry’’ is often maintained in classrooms where developmentally oriented teaching subtly controls what is said and done.

Even when the whole-class questioning exchanges were of the IRE or IRF structure, they pushed students to articulate and elaborate on what they were thinking. Thus, despite being much criticized by researchers observing classroom talk (e.g., Lemke, 1990), IRE or IRF can allow whole classes to talk together, and is a sort of large-scale scaffolding (Dawes, 2004). In this regard, the questioning approaches identified in this study could be considered as one variation of an inquiry-based pedagogy that is adapted to teaching large classes, where students engage in scientifically oriented questions posed by the teacher, and where teachers serve as resources of questions and guidance for student learning. As Songer, Lee, and McDonald (2003) have pointed out, the nature of inquiry science teaching can vary according to class size, and we need to expand our understanding of classroom inquiry beyond the idealized model of small, autonomous groups engaged in self-guided activities.

The questioning strategies used by the teachers in this study were situated within a social-cultural context where views of educational practices are influenced by both Eastern and Western philosophies, resulting a hybrid pattern of teaching and learning. In attempting to adopt teaching practices that are commonly advocated in the West (e.g., learner centered, small-group, collaborative approaches), Singaporean teachers are constrained by having to deal with large classes. At the same time, because of the cultural heritage of the country, Confucian views of teaching and learning also prevail. In the latter model of teaching-learning, the teacher is regarded as a master, virtuoso performer, and coach (Ko & Marton, 2004; Paine, 1990; Pratt, Kelly, & Wong, 1998), and this serves as a guiding social principle for the conduct of classroom discourse. Consequently, compared to Western school settings, whole-class teacher talk is more common since students are less willing to speak up, lest they be perceived as wanting to assume authority comparable to that of the teacher (Pratt, 1992).

Despite the negative implication of this model where the teacher is perceived to be active whereas the students are passive, some authors (e.g., Stevenson & Lee, 1997) have argued that this whole-class instructional method, with a focus on teacher talk, allows each student to have the maximum opportunity to benefit from the teacher and to enhance conceptual understanding; and this may be one factor that contributes to the excellent performance of students from several East Asian countries in international science assessments. Thus, although the students in these classrooms may appear as passive members of a large audience, they may be actively participating in thought-provoking tasks mediated by teacher questioning (Biggs, 1996; Cortazzi & Jin, 2001).

Chin (2006) has suggested that particularly in such classroom settings where students are less inclined to verbalize their ideas publicly, unless solicited, it is important that teachers acquire ‘‘responsive questioning and feedback’’ skills in eliciting, probing, and extending students’ thinking, so as to provide both linguistic and cognitive scaffolding for students as they are guided towards successively higher levels of thought. From this perspective, and using the metaphor proposed by Ko and Marton (2004), we could ‘‘see the teacher as the director, and the students as the actors playing in accordance with a script that they have never seen’’ (p. 62). Thus, classroom instruction is both teacher-centered and student-centered, as both teacher and students participate in a collaborative and shared ‘‘space of learning’’ (Marton & Tsui, 2004).

Asking questions that guide students towards productive thinking is not an easy task. First, the teacher has to have a good understanding of the subject matter so that she can ask the appropriate questions to help students integrate the different concepts into a conceptual framework of interconnecting concepts rather than present them as isolated facts. Second, she has to have the pedagogical skills in crafting and sequencing the appropriate questions that progressively build on previous ones. Third, to teach using a series of questioning sequences, she must also be able to get the co-operation of her students who may prefer to play a passive recipient role in science lessons. Fourth, the concern to cover the prescribed examination syllabus within a tight time schedule may militate against such questioning practices, which take up much time.

Limitations

One limitation of this study is that, in the analysis and interpretation of classroom discourse, the linguistic form (verbal data) was used as a predominant marker of interactional or cognitive function, and is thus at best, inferential. This methodological issue was raised by Barnes and Todd (1977, 1995). A second limitation relates to the generalizability of each respondent’s utterance to the rest of the students. Much of the data in this study was derived from discourse in whole-class settings. However, at any moment in time, there can only be one person responding to the teacher, except in the case of chorus answers. The analysis and interpretation of data was based on the utterances and responses of individual members who participated in the verbal exchanges, but collectively extended to the class as a whole. The assumption was made that whatever applied to the individual respondents also applied to the other students in class. This assumption has limitations as the process of internalization does not simply involve direct transfer from social to personal planes and it is not possible to know for sure, the extent to which individual students were able to internalize and make sense of the concepts addressed.

A third limitation of this study pertains to the omission of questioning strategies that relate to epistemic thinking. The questioning strategies identified in this study were concerned mainly with promoting students' knowledge and conceptual understanding of science content, and less so with guiding students' epistemic thinking. To fill this void, future research could focus on how teachers pose questions that aim to help students understand how scientific knowledge is produced.

Significance of Study

Recent studies in science have focused on the characteristics of classroom talk and questions that facilitate productive thinking in students (e.g., Abell, Anderson, & Chezem, 2000; Crawford, Kelly, & Brown, 2000; Gallas, 1995). This study contributes to the growing literature on the nature of dialogue during science instruction that facilitates student thinking. Questioning is an integral part of good teaching. However, despite its prevalence and importance, fine-grained analyses uncovering the details of this practice are rare. While several categories of teachers' questions have been proposed by others, they have focused on individual questions. These include Bloom's taxonomy (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956), open and closed questions (Blosser, 1973; Carr, 1998), productive questions (Elstgeest, 1985), operational questions (Alfke, 1974), and questions based on mental operations (Koufetta-Menicou & Scaife, 2000). The characterization of teacher questioning approaches in this study contributes to an understanding of how different individual questions are woven holistically into everyday instruction, how they influence subsequent student responses, and how they can stimulate productive thinking in students as part of a teaching sequence across different classroom activities such as direct instruction, whole-class discussions, and laboratory investigations.

The typologies of questioning approaches developed here are different from the above-mentioned taxonomies produced by other researchers in that the focus is not on the questions alone, but also on how the questions are related via strategic discourse moves that work purposefully towards the teachers' ultimate teaching goals. When used together with the question types and strategies described by other authors, the questioning approaches and accompanying strategies identified in this study provide a comprehensive and conceptually grounded framework within which teachers can work, as they conceptualize and pose their questions.

The findings from this study have potential in translating research insights into practical advice for teachers regarding tactical moves in classroom discourse. Because such discursive teaching strategies have been tacitly employed by teachers, they have generally been invisible to others. The analysis of talk data derived from classrooms can enlighten instructional practice, raise awareness of the range of discursive strategies available, and serve as useful feedback for teachers during pre-service training and in-service professional development. The ability to manage and orchestrate classroom discourse to support student learning is an important aspect of pedagogical content knowledge (Shulman, 1986). Thus, a practical significance of the findings of this study lies in making explicit, the different ways in which questions can be framed in the classroom to support student learning in science.

Conclusion

This study provides specific examples of questioning approaches that are potentially useful to teachers who are interested in honing their discursive skills and in adopting ways of questioning and classroom interaction that foster productive student responses. The framework developed here can provide a guideline for science teachers to increase their repertoire of questioning skills and serve as a heuristic for them to shift their classroom discourse toward more constructivist-based practices.

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