Teacher Questioning in Science Classrooms: What Approaches 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. Six teachers teaching secondary 1 science classes 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. In the analysis of classroom discourse, 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 productive 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.

Teacher questions are a frequent component of classroom talk and 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 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.

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 of the teacher assisting student performance through the "zone of proximal development" (Vygotsky, 1978). 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 conveys 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. An alternation between these two types of discourse is important for developing conceptual thinking (Mortimer, 1998).

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. Instruction is primarily didactic via "teaching by telling" and the purpose is to deliver information as efficiently as possible. 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.

Previous Research on Teacher Questioning

Teacher questioning is a prominent feature of classroom talk. Previous studies on teacher questioning focused on the IRE (Initiation, Response, Evaluation) pattern of discourse (Mehan, 1979) and the importance of wait time in increasing students' thoughtfulness (Rowe, 1986; Tobin, 1987). In IRE, 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 predominant in classrooms, and the teacher's questions are usually pitched at recall and lower-order thinking. However, this pattern of discourse is sometimes also known as the IRF, representing initiation, response, and follow-up (Sinclair & Colthard, 1975), as the third move may not necessarily be an explicit evaluation. The study by Chin (2006), for example, identified four different types of teacher feedback following a student's response.

The purpose of teacher questioning in traditional lessons is to evaluate what students know. However, in classrooms where the focus is on constructivist-based instructional approaches, 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. The teacher adjusts questioning to accommodate students' contributions and respond to students' thinking in a neutral rather than evaluative manner.

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. By establishing this pattern of discourse, the teacher is able to explore students' ideas. Roth (1996) described a case study where the teacher's questioning was designed to "draw out" students' knowledge, and to scaffold students' discursive activity. 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 questions 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.

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). As teacher questioning is an important aspect of instructional scaffolding, 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, and to identify different ways of teacher questioning that encourage productive thinking in students.

Methods

Six teachers from four schools teaching secondary 1 (12-13 year olds) science 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. The average class size was 40 students per class. The students were generally motivated, on task, and ranged from average to above-average ability. 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.

Thirty-six lessons were observed and they covered a range of topics including measurement; mass, volume, and density; elements, mixtures, and compounds; materials; photosynthesis; respiration; cells; and genetics. The lessons were audiotaped and videotaped. Primary 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 provided additional information about classroom contexts. Discourse involving teacher-student talk was transcribed verbatim. Video-clips of the lessons were observed and interpretive notes were made.

Verbal data from the transcripts were analyzed interpretively. Particular attention was paid to questioning exchanges that stimulated productive thinking in students, as manifested by their verbal responses. 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. 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. Codes were developed that represented the teachers' questioning approaches and strategies, and subsequently tested in the remaining body of verbal data. They were then refined through an iterative process until a useful and comprehensive scheme emerged that covered the entire database (Bogdan & Biklen, 1992).

Results

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.

Socratic Questioning

In Socratic questioning, the teacher used a series of questions to prompt and guide student thinking. 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.

<u>*Example 1 (Pumping)*</u>. Pumping 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?").

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 coloured 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.

Example 2 (Reflective toss). 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 (van Zee & Minstrell, 1997). In a lesson on photosynthesis that involved testing a green leaf for the presence of starch, the students noted that the leaf had to be immersed into a boiling tube half-filled with alcohol until it lost its colour. When a student asked how the chlorophyll could be removed from the alcohol, the teacher R counter-questioned by asking "*How are you going to remove the alcohol from the green solution?* …. *Can you recall your separating techniques? What will you use?*" to which another student replied "distillation". The students subsequently explained that "vapour is formed" and that a "green colour" would be left behind.

Example 3 (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 this 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 then compared three different methods proposed by the students. As the students spoke, teacher L used the board to draw labelled diagrams that corresponded to the students' descriptions.

A student suggested using a measuring cylinder to first measure the volume of water only, and then measure 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 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) (Method 2). 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 the 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 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.

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, and to reinforce scientific vocabulary, particularly when the topic was associated with a number of technical terms. The teachers' questions served to elicit the appropriate and essential words from students for the construction of declarative knowledge in the form of propositional statements that were integrated to form a network of related concepts.

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 [pause]?*". Another strategy, association of key words and phrases is given below.

<u>Example 4 (Association of key words and phrases)</u>. 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 labelled from a to f 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.

After the students had completed the task in pairs, teacher S used a transparency to guide a whole-class discussion on the stages involved in mitosis. She posed questions that guided students to correctly identify the sequence of steps involved during cell division. Then she 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 key words on the transparency, and then highlighted them by underlining them.

T: Some of the key words. 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 key words?*
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 helped 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.

Semantic Tapestry

Features of this questioning approach include multi-pronged questioning, stimulating students' use of multimodal thinking, as well as focusing and zooming.

<u>Example 5 (Multi-pronged questioning)</u>. 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. For example, in a lesson on 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.

When giving students a textual description of the leaf, the teacher posed questions such as "*What name is given to each of the plants described below?*", and "*So what is the very first question that you'd go to?*". Then she prompted students with specific questions pertaining to physical features such as the shape, venation pattern, type of leaf tip, and the presence or absence of hairs -- "*Are the leaves long and thin?*", "*Do the leaves have parallel veins?*", "*Does the leaf have a pointed tip?*", and "*Does the leaf have hairs?*".

When students were given drawings of leaves, Teacher S then asked for a verbal description by asking "*What's the name of this plant?*" and an open question "*How do you describe this leaf?*" which required students to be more generative in their thinking. A student then responded with the descriptions "long and thin", "parallel veins", "non-pointed", and "non-hairy", to which Teacher S asked "H*ow do you tell that it's hairy or non-hairy?*".

Teacher S then asked the students how they would draw a 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 asked "*How would you describe JANG [leaf]*?" and subsequently called a student to the board to draw how he thought the leaf would look like.

In responding to the teacher's questions, the students had to translate information between written, verbal, and visual forms of representation. They had to communicate their understanding not only verbally but also in diagrammatic form.

<u>*Example 6 (Stimulating multimodal thinking)*</u>. 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.

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 asked students what happens to ice in the ice-tray when water freezes. She asked questions such as "*If ice floats on water, as we always notice, what does it tell you about the density of ice?*", "*Why is ice less dense than water?",* "*When ice freezes, what actually happens?*", "*And when it expands, what happens to the volume of ice?*", and "*Sink in or bulges out?*".

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. She asked questions such as "*And in expansion, which quantity changes?.... The volume increases or decreases?*", "*Which quantity doesn't change?*", "*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?*", "*So what has happened to the density? The density is now more or less?*". In this way, students could see that the numerical value for the density of ice was lower than that of water.

Finally, teacher L tapped into students' visual thinking where students could use their "mind's eye" to evoke mental images. The questions that she asked included "*When the volume of this same* *mass increases… what happens to the molecular packing? Are the molecules still as close as before?*", "*More spaced out? Closer?*", "*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?*", and "*What will happen, therefore, to the mass per unit volume? Increase or decease?*"

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. 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.

Example 7 (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.

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.

In a lesson on designing and performing an investigation to find out the effect of surface area of a solute (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?*"), carrying out the steps of the procedure (e.g., "*Measure how much?*"), recording of results (e.g., "*How would you put [display] your table?*"), 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?*").

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 and perspectives, thus leading to a deeper understanding of the subject matter. Unlike the verbal jigsaw described above, it lends itself well to topics that are not associated with an abundance of technical terms. 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.

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. Question-based prelude was characterized by a number of question-answer propositions in expository talk. The questions acted as a preface to presenting subsequent 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.

Example 8 (Question-based outlines). For question-based outlines, 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.

In an introductory lesson on respiration by teacher R, students first discussed given tasks in groups and then presented their answers to the class. Each problem was presented on PowerPoint slides and also on handouts in the form of an overarching trigger question as the title of the task, followed by a series of sub-questions. 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?. Each group of students used the questions to focus their discussion and found out the answers to the given questions themselves. A group representative then gave a presentation to the class. The questions served to scaffold students' thinking and guided them in their search for information about the topic in hand.

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 stimulated 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.

Example 9 (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.

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

Discussion

The objective of this study was to characterize the underlying structure of talk and, in particular, the questioning approaches adopted by teachers that encouraged productive thinking in students. Examples of ways of questioning that helped teachers make their classroom discourse more though-provoking were provided.

Implications for Instruction

When using Socratic questioning, the teacher acted as an interlocutor who posed guiding questions to lead students to construct their own meanings. Students contributed their ideas and answered questions during the lesson to advance the discussion, rather than having the teacher provide all the information. For verbal jigsaw, the focus of teacher questioning was on students' use of the appropriate scientific vocabulary, key words and phrases. This approach is suitable for topics that are laden with a number of technical terms and descriptive phrases and particularly appropriate for students with weak language skills. As for the approach termed semantic tapestry, the strategies aimed to help students make meanings from different angles, across different modes, and from both macro and micro perspectives. Because students have different learning styles, multi-pronged questioning and stimulating multimodal thinking can also tap into students' multiple intelligences (Gardner, 1999) that involve the use of verbal, visual, logical-mathematical and other modes of thinking.

In using framing as a questioning approach, the questions make explicit, the "what-why-when-which-how" relationships among the concepts addressed. The subordinate questions nested within a more general overarching question in question-based outlines 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.

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).

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.

Significance of Study

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. The characterization of teacher questioning approaches in 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. 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.

Note:

Because of space restrictions, several details of excerpts from classroom talk have been omitted here. A fuller version of this paper is available in a forthcoming publication (Chin, in press).

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