Education Journal《教育學報》*, Vol. 29, No. 2, Winter 2001*

Learning in Science: What Do Students' Questions Tell Us About Their Thinking?

CHRISTINE CHIN
National Institute of Education, Nanyang Technological University, Singapore

The purpose of this study was to (1) study how students' questions contribute to the knowledge construction process, and (2) relate the nature of students' questions to their approaches to learning. Six Grade 8 students were observed during class activities, and interviewed before and after instruction about related science concepts. Students' questions included basic information questions which reflected a surface learning approach, and wonderment questions which characterized a deep approach. While wonderment questions stimulated the students themselves or their peers to hypothesize, predict, thought-experiment and generate explanations, basic information questions elicited little conceptual talk or deep cognitive processing. Although the students did not always ask wonderment questions spontaneously, they were able to generate such questions when prompted to do so. Some strategies related to student questioning that teachers can use to encourage deeper thinking in students are suggested.

Questioning is an integral part of scientific inquiry and the learning process. Students' questions can reveal much about the quality of students' thinking and conceptual understanding (Watts & Alsop, 1995; White & Gunstone, 1992; Woodward, 1992), their alternative frameworks and confusion about various concepts (Maskill & Pedrosa de Jesus, 1997), their reasoning (Donaldson, 1978), and what they want to know (Elstgeest, 1985). Student questioning, particularly at the higher cognitive levels, is also an essential aspect of problem-solving (Pizzini & Shepardson, 1991; Zoller, 1987).

Self-questioning is also considered to be a metacognitive activity (Wong, 1985), and is consistent with the view of generative learning (Osborne & Wittrock, 1983, 1985) as learners try to reconcile their prior knowledge and new information in their attempts to make sense of these ideas. Despite the educational value of students' questions, Dillon (1988) found that students asked remarkably few questions, and even fewer in search of knowledge. Few students spontaneously ask high-quality thinking questions (White & Gunstone, 1992, p. 170), and low levels of questioning and explanation on the part of students were found to be correlated with lower achievement (Tisher, 1977).

Most of the earlier research on student-generated questions in science focused on students' reading comprehension of text-based questions (e.g., Koch & Eckstein 1991; Pearson, 1991) with less research on non-text-based questions. For example, Koch and Eckstein (1991) found that there was improvement in the reading comprehension of college physics students when they were taught the skill of formulating questions on textual material. Scardamalia and Bereiter (1992) found that non-text, knowledge-based questions which reflected things that students genuinely wondered about in an effort to make sense of the world were of a higher order than text-based questions. These questions were significantly superior in their potential contribution to knowledge, in their focus on explanations and causes instead of facts, and in requiring more integration of complex and divergent information.

More recent studies of student-generated questions in science have focused on the nature of these questions (Watts & Alsop, 1995; Watts, Gould, & Alsop, 1997), the characteristics and influence of students' questions on investigative tasks (Keys, 1998), the use of students' questions as indicators of their learning problems (Maskill & Pedrosa de Jesus, 1997) and as an alternative evaluation tool (Dori & Herscovitz, 1999), and the difficulty that students have in asking questions about abstract concepts (Olsher & Dreyfus, 1999).

Watts and Alsop (1995) found that students' questions were diagnostic of the state of students' thinking, revealing their frames of reference and unorthodox understanding of science, and being indicative of the routes through which students were seeking understanding. Three categories of students' questions seem to illuminate distinct periods in the process of conceptual change (Watts, Gould, & Alsop, 1997). These include (1) consolidation questions where students attempt to confirm explanations and consolidate understanding of new ideas in science; (2) exploration questions where they seek to expand knowledge and test constructs; and (3) elaboration questions where students attempt to examine claims and counter-claims, reconcile different understandings, resolve conflicts, test circumstances, and track in and around the ideas and their consequences.

Keys (1998) found that when Grade 6 students worked in groups to generate their own questions for open-ended science investigations, they mainly varied the teacher-directed activity by essentially repeating the activity but changing one or more of the variables, or invented questions from their own imaginations based on their ideas from previous science lessons and personal experiences from everyday life. Students' questions determined the depth and breadth of the concepts to be learned, the scientific processes to be used, and the cognitive difficulty of the investigation tasks. Allowing students to generate their own investigation questions stimulated curiosity and encouraged profound thinking about relationships among questions, tests, evidence, and conclusions.

In the study by Maskill and Pedrosa de Jesus (1997), the teacher stopped the lessons from time to time and requested the students to write down any questions they wished to ask about problems they were having. The questions provided information about students' learning difficulties and served as useful feedback for future teaching. In the study by Dori and Herscovitz (1999), Grade 10 science students posed questions while practicing a variety of learning activities. The students' question-posing capability was then evaluated by giving the students a case study and asking them to compose as many questions as they could about the case they had read. There was a significant increase in students' question-posing capability after instruction (as indicated by the total number, orientation, and complexity of questions). The findings also showed that question-posing capability can be used as a means of evaluating higher-order thinking.

Olsher and Dreyfus (1999) found that the number of questions that junior high school students could ask about abstract concepts and "black box" molecular biochemical processes was limited compared to questions pertaining to the clarification of terms or which referred to the human and social aspects of the uses of biotechnologies. However, after some intense scaffolding, the students were able to ask questions relevant to the processes at later stages of the lesson.

The findings from the above-mentioned studies indicate that there is substantial educational potential in student-generated questions in directing students' inquiry and guiding their construction of knowledge. Most earlier studies (such as those concerned with text-based questioning) adopted a process-product approach, typically comparing the effects of an intervention with a comparison group and focusing on student achievement. More recent studies, however, have used a sociolinguistic approach which emphasizes the interactional nature of classroom discourse and social contexts. Carlsen (1991) suggested that three features of questions (viz. context, content, and the responses and reactions by speakers) can be considered in sociolinguistic research on classroom questioning which can address the dynamics and active construction of meaning that the process-product paradigm is unable to consider.

Previous studies focused primarily on questions produced individually, and in written form. Little research has been done to investigate the role of students' questions in the knowledge construction process, especially in classroom discourse. It is thus of interest to study how questions produced both individually and in a group setting scaffold and interact in students' collaborative inquiry, and help in the construction of conceptual knowledge. Accordingly, the purpose of this study was to (1) study how students' questions contribute to the knowledge construction process, particularly in educational discourse in small-group collaborative settings, (2) relate the nature of students' questions to their learning approaches, and (3) suggest some strategies related to student questioning that teachers can use to promote deeper thinking in their students.

Design and Methods

A case study approach (Merriam, 1988; Stake, 1995) of six Grade 8 target students from a school in a U.S. mid-western university town was used. Purposive sampling of a few target students allowed the tracking of selected individuals over time, as well as the collection of rich, in-depth data from classroom discourse in small-group settings for subsequent detailed analysis. The students represented learners of different academic abilities as well as those typically using learning approaches ranging from deep to surface, as identified by the Learning Approach Questionnaire (modified from Entwistle & Ramsden's [1983] instrument) and their teacher's evaluation of their school work. To ensure validity in the choice of students, it was important that the teacher's evaluation matched the students' scores on the questionnaire. Other selection criteria included: good attendance, being verbally expressive and on-task, having at least average success in science, and having the ability to work well with each other.

The science class was observed for nine weeks during the instruction of a chemistry unit. The six students worked in two groups of three during their class activities. The group members were assigned by the teacher who in the past had experienced greater success with same-sex groups. The boys' group consisted of Rick, Quin, and Carl while the girls' group comprised Mary, Bess, and Dale. Rick and Mary were identified as learners who used a predominantly deep learning approach, Carl and Dale as learners who typically used a more surface approach, while Quin and Bess used an approach that lay somewhere between a deep and surface approach. The topics covered in the chemistry unit included the nature of matter (elements, mixtures, compounds, atoms and molecules), states of matter and changes of state, physical and chemical changes, acids and bases. The five hands-on laboratory activities that were conducted during these nine weeks, and for which all six students were present include the following:

1. *Separation of Salt-Sand Mixture*: This was an open-ended problem-solving activity where the students had to devise a method for separating a mixture of salt and sand.
2. *Boiling Point Laboratory*: The students had to plot and compare the temperature graphs for plain water and salt water when ice and salted ice were heated until boiling.
3. *Chromatography*: The students used paper chromatography to separate the dyes in the ink from different colored marker pens and calculated the retention factor (R_f) for each dye.
4. *Chemical Change: Reaction Between Zinc and Dilute Hydrochloric Acid*: The teacher gave a demonstration on how to carry out the activity. The students then performed the activity individually in their groups.
5. *Acids and Bases*: The students were required to determine if some common household substances (vinegar, baking soda, water, salt water, ammonia, aspirin, antacid tablets, alcohol, bleach, coca-cola, coffee, mouthwash, and lemon juice) were acidic, basic, or neutral, using cabbage juice and blueberry juice as indicators.

Except for the first activity on the separation of a salt-sand mixture, the students were given verbal procedures for the other activities.

The boys were audiotaped and the girls were videotaped during the science hands-on activities, and both were encouraged to think aloud and to verbalize their thoughts. Field notes were taken. The students were also interviewed individually after instruction of the chemistry unit to find out more about their understanding of the science concepts in this unit. The interviews were audiotaped. Stimulated recall was used to obtain further information about how the students tackled the tasks and what they were thinking of while engaged in the laboratory activities. This provided information about silent thoughts which were not always verbalized and captured on tape.

To find out if the students had other questions that were not verbalized during the activities and thus not captured on tape, the students were asked to write down at home any questions they had, as part of a learning journal, particularly about things that puzzled them. For the boiling point activity, the teacher also set aside time during the lesson for the students in class to write down questions. During the post-instructional interviews, the students were also asked if they had any questions pertaining to the hands-on activities.

Data from multiple sources (field notes, transcripts of classroom discourse from the audiotapes and videotapes, audiotaped interviews with the students, and students' written work) were analyzed in relation to each other; this served to triangulate the data and to help enhance the credibility of the findings and assertions made (Lincoln & Guba, 1985; Stake, 1995). The target students' taped interviews and discourse during class activities were transcribed verbatim and subsequently analyzed. Transcribed discourse from the videotapes was also supplemented with descriptive notes obtained by viewing the videotapes to get information about what the students did during the laboratory activities.

To identify the types of questions that students asked, the transcripts were read through several times. Coding categories (Bogdan & Biklen, 1992) were then developed by making annotated descriptive and interpretive comments on the margins of the transcripts each time a question was documented. These became the tentative coding categories. Subsequent transcript segments containing questions were then annotated with the appropriate code. 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. Segments of the transcript following the questions were scrutinized to study the evolution and progress of students' thinking and actions during their knowledge construction process. Assertions were made based on patterns observed which were grounded in the data.

Results

The Nature of Students' Questions

The types of questions that students asked were identified, and details regarding this information are presented elsewhere (Chin, Brown, & Bruce, in press). In summary, students' questions could be broadly classified as basic information questions and wonderment questions (c.f., Scardamalia & Bereiter, 1992). Basic information questions comprised factual and procedural questions. Factual questions were often closed questions, usually requiring only recall of information, and typically relating to information in the textbook or some simple observation made about an event. Procedural questions attempted to clarify a given procedure or asked how a task was to be carried out especially when step-by-step instructions had been given.

Wonderment questions, which were pitched at a conceptually higher level, included: (1) comprehension questions which typically sought an explanation of something not understood; (2) prediction questions of the "What would happen if …" variety involving some speculation or hypothesis-verification; (3) anomaly detection questions where the student expressed skepticism or detected some discrepant information or cognitive conflict, and sought to address this anomalous data; (4) application questions in which the student wondered of what use was the information that he or she was dealing with; and (5) planning or strategy questions where the student was temporarily stuck and wondered how best to proceed next when no prior procedure had been given.

Most of the questions that the students asked during the hands-on activities were generally not of a conceptually high level that manifested deep thinking. Procedural questions formed 65% of all questions asked. Wonderment questions comprised only 14% of all the questions asked, with half of the wonderment questions being comprehension questions which focused on explanations. Chin, Brown, and Bruce (in press) also found that the open-ended problem-solving activity on separating a salt-sand mixture elicited more and a wider range of wonderment questions than teacher-directed activities such as the one on zinc-hydrochloric acid chemical reaction which was carried out more in the form of an illustration or a verification rather than in the spirit of inquiry.

The Role of Students' Questions in Knowledge Construction

The type of questions that students asked influenced the nature of the responses elicited and thus, the kind of thinking that students subsequently engaged in. Examples based on four laboratory activities will be presented.

Activity on Acids and Bases

Consider the following segment from the activity. Most of the talk was procedural and involved recording color changes and noting the number of drops of solution added.

Carl:	*How many drops [of cabbage juice indicator] did you put in?*
Quin:	… 6, 7 … [ignoring Carl and counting the number of drops to himself]
Carl:	30?
Quin:	… 9, 10, 11, 12, 13, 14 … Almost done. *And what are we supposed to do next?*
Carl:	Add some stuff that Rick is getting.… Put them in till it changes color.…
	[Rick added aspirin to one of the test tubes.]
Rick:	This is aspirin…. Well, there it goes. It's changing color.
Carl:	It's purple.… *How many did you put in?…*
Rick:	Five drops.

The students then tested ammonia solution, coca-cola, mouthwash, bleach, alcohol, lemon juice, baking soda, and water with the cabbage juice indicator. The author (CC), who observed the lessons, then asked the boys what sense they were making out of their observations.

CC:	Why do you think the solutions are changing color?
Quin:	I don't know … chemicals mixing.
Carl:	The different chemicals, they are just reacting.

The above excerpt shows that basic information (factual and procedural) questions were typically either ignored or simply responded to with a short, simple answer without leading to further conceptual talk. They had little effect on students' subsequent cognitive behaviors, and engendered little productive discourse, thereby contributing little to knowledge construction. The students had merely been following the teacher's instructions without understanding much of what was happening, and were thus unable to explain why the solutions changed colors.

Activity on Separating a Salt-Sand Mixture

This activity was problem solving in nature and carried out in the spirit of inquiry. Quin first asked a prediction question "*How about we pour some* *water in here?*" that was of a speculative nature as he did not know what exactly was going to happen then. After some discussion, the students followed up on this question by pouring water into the beaker containing the salt-sand mixture and stirring it with a spoon to see what would happen. Quin asked a comprehension question "*What do you all think the water is going to do?*" as he was still unsure of the purpose of adding water. He then answered his own question by offering the explanation, "I think water absorbed the salt," and Carl elaborated on this by saying, "The dirt [sand] didn't dissolve, so the dirt separated.… The salt dissolved. It's in there." As the dissolved salt was no more perceptible, Rick asked Carl an anomaly detection question: "*How do you know it's in there?*" He wanted Carl to provide evidence for this and said, "Take a test."

After he had drained the salt solution from the wet sand, Quin noticed that there was no more salt mixed with the sand. This prompted him to ask another comprehension question "*A lot of sand, but where did the salt go?*" as he tried to fathom what had happened to the salt, to which Carl replied, "It's in the water." Quin wondered how he could recover the salt from the salt solution and further posed a planning or strategy question: "*How are we going to bring it back?*" The boys were stuck for a while. Quin's question then stimulated Rick to think of the possibility of heating the salt solution. In this case, a student's (Quin's) question triggered off deep thinking processes in a peer, and helped him (Rick) to figure out a solution to the problem. This shows the effect of social interaction on stimulating a student's use of strategies which had hitherto been perhaps latent. Finally, the boys managed to recover the salt by heating the salt solution over the alcohol burner.

When Rick asked Quin what he was thinking of when the salt soluion was being heated, Quin said that he was trying to "melt" the water. Carl corrected him by suggesting that "evaporate" would be a more appropriate word as the water was "boiling." Rick then demonstrated uptake of this information by adding that "the salt will stay there." There was co-construction of knowledge during the group interaction when the boys refined each other's ideas. The above example shows the potentially powerful effect of wonderment questions in stimulating further thinking in the questioner himself (viz., Quin) and those who were engaged in conversation with him (viz., Rick). These questions, which arose because of the students' speculation or puzzlement, served to direct further inquiry and elicit explanations of what was going on. Thus, unlike basic information questions, wonderment questions tended to elicit responses that were of a more conceptual nature.

The girls first tried to use a magnet, a sifter, and to create static electricity, all without success. Then Bess asked a comprehension question “Salt water comes onto beaches. *How does the salt stay there?*” which stimulated Mary to think of ideas that led her to a “breakthrough,” a moment of insight. Mary later explained that at that moment, she began to think of a previous experience at her grandmother’s beach-house, and tried to make a connection between the sand, salt, water, and heating in the current activity and the beach sand, salt on the rocks, ocean waters, and hot sun by the sea. This subsequently led her to apply her understanding of concepts related to dissolving and evaporation, and to solve the problem by adding water to the salt-sand mixture, decanting the salt solution from the wet sand, and then heating the salt water with an alcohol burner to evaporate the water and recover the salt.

Wonderment questions, unlike basic information questions, have potential in stimulating talk at a higher cognitive level which would help students construct relevant conceptual knowledge. These questions could help direct further inquiry and trigger deeper thinking in students as they discuss their ideas and follow up on their questions. As shown in the examples given above, a prediction question can stimulate students to test their assumptions and compare if their observations match their speculations. A comprehension question can stimulate students to generate their own explanations for things which puzzle them, while a planning or strategy question can stimulate students to figure out how to solve a problem.

Boiling Point Laboratory

This activity was relatively procedural and did not engender much conceptual talk. Most of the statements made by the students were procedural and observational in nature, and few wonderment questions were asked. The procedural statements included: “Record this temperature”; “Look on the bottom and see if it’s like going to be small bubbles”; and “She [teacher] said stir it with a spoon.” The observational statements included: “Temperature’s rising”; “See the water evaporating”; and “It’s starting to bubble.” The students, though puzzled by some observations, did not ask many questions because they were too engrossed in getting the tasks done in the time required. Even when a question was asked, there was little follow-up discussion as the students busied themselves with carrying out the prescribed procedures.

Data about students’ questions from students’ learning journals, the post-instructional interviews, and a class writing session where students wrote questions showed that the students did have more questions beyond those verbalized during the activity. When asked to think about what had puzzled them and to ask questions about the activity, the students became more aware of what they did not understand or had not thought of earlier. Dale wanted to know "Why [does] salt water get hotter?". Bess was surprised to note the formation of bubbles at temperatures below 100 ºC, and wanted to know "Why did the water boil below the boiling point?". Quin was puzzled about why the temperature stayed constant at the boiling point.

Although Carl did not ask any wonderment questions during the activity itself, he had some interesting ideas when he wrote the questions in class and in his learning journal. He wrote "I learnt the temperature is more extreme when you add salt" and "It was amazing when water boiled below the boiling point." His latter idea probably referred to the formation of bubbles below 100 ºC. He also wrote "I would like to experiment not only with salt but with sugar" and wondered "if it would be different temperatures if we used an alcohol burner instead of a hot-plate."

Because there was no whole-class discussion by the teacher after this laboratory activity, some concepts pertaining to the various related phenomena and the questions raised by the students were not addressed. The above findings suggest that students do not always ask wonderment questions spontaneously. Unless teachers encourage students to ask questions by deliberately incorporating question-asking activities in the lesson plan, many of the students' questions and puzzlement may go undetected and not be dealt with. Several suggestions of how teachers can encourage student questioning are given in a later section.

Chromatography Activity

After the boys had spotted the different ink colors on the filter paper strips, they left the strips to stand. Up till then, they had merely been engrossed with following procedures, had been engaged in conversation of only a procedural nature, and had not discussed anything about the separation of colors in the developing chromatograms. So the author (CC) decided to find out how they would interpret this observation.

CC: I notice the colors are spreading. There are different shades now.…

Quin: *Where's the dot [initial ink spot]?*

Carl: The dots are gone! …
CC: What do you think is happening? Why do the dots go away?
Rick: They travel in the water.
Quin: Water is traveling up the paper. It made the color spread.
CC: Mrs. Jones was talking about the molecules. How do you think that actually happens?
Quin: The water attract the molecules.
Rick: They connect and then they move up with each other.
Quin: Move up. Gets to the top so it would attract all the others.

The author's remark about the spreading colors stimulated Quin to ask "Where's the dot?" (a wonderment question) and Carl to notice with surprise, that the "dots" had disappeared. Prior to this, the boys did not ask any wonderment questions or engage in conceptual talk. However, subsequently when the author asked the boys "Why do the dots go away?", they attempted to explain what was happening to the colors. This episode reflects the importance and facilitative effects that scaffolding has on students asking questions.

In his learning journal, Rick wrote "We found out what different colors had to be mixed to form one." He wanted to know "Why do they [ink spots] separate like that?" and "What do these [R_f] numbers mean?". Carl had three interesting wonderment questions. First, he wanted to know "Why do some pen [ink] run faster than others?". This indicated that he was wondering why the component ink colors had traveled different distances along the filter paper strip. Second, he wanted to know "Why did some change colors and others didn't?", as he was puzzled by why some of the component ink colors were of a similar color to the original ink spot whereas others were different from the original one. The third question he asked was "If you put more than one color [on the spot], would it separate into just more [colors]?".

This last prediction question was like a thought experiment involving conjecture where Carl wondered what would happen if two ink colors were mixed together in the original spot. What was interesting about Carl was that he was able to ask some thoughtful wonderment questions when he was specifically requested to ask questions after doing the activity. Among the girls, Dale had no further questions, Bess wanted to know what the R_f values meant, and Mary asked "What is the R_f used for?" (an application question).

These findings further reinforce the point that wonderment questions may not always be asked spontaneously by students, especially if the students are too preoccupied with following given procedures and not thinking deeply about what is going on during the activity. Most of the wonderment questions asked during the activities came from Quin, Rick, and Bess. Carl and Dale, who used a predominantly surface approach to learning hardly asked any wonderment questions while performing the activities. Although this is not surprising, what was unexpected was that when the students were specifically instructed to ask questions, Carl was able to come up with some meaningful wonderment questions. This suggests that even students who do not typically ask higher-level wonderment questions spontaneously are capable of doing so if given the time and encouragement.

Discussion, Implications, and Conclusions

This study identified some of the types of questions that students should be encouraged to ask to bring about deeper learning and meaningful knowledge construction. Such a taxonomy of question types, which classifies students' questions according to different conceptual levels, would be useful in helping teachers plan their activities so as to foster student questioning at a higher cognitive level.

One limitation of this study is that the findings were based on only six students from the same class taught by one teacher. The findings are thus presented as grounded hypotheses rather than generalizable findings. Another limitation is that some of the students' questions may not have been verbalized or thought-aloud during the hands-on activities, and thus were not documented for subsequent data analysis. However, attempts were made to maximize the collection of data on students' questions through stimulated recall during post-instructional interviews and written questions.

How Students' Questions Contribute to Knowledge Construction

Basic information questions did little to stimulate deep thinking in students, and elicited only short responses which dealt with factual and procedural information. On the other hand, wonderment questions facilitated knowledge construction by guiding thinking and promoting conceptual talk that pertained to the core concepts of an activity. It was found that such questions stimulated not only the students themselves, but also their group members to hypothesize, predict, seek and generate explanations for things which puzzled them. This is evident in the activity on separating a salt-sand mixture — in the boys' group, Quin asked wonderment questions which stimulated both Rick and himself to generate responses, while in the girls' group, Bess' question stimulated Mary to respond. That is, these questions triggered the use of deep thinking strategies which may not be invoked if these questions had not been asked. The questions played an important role in engaging the students' minds more actively, engendering productive discussion, and leading to meaningful construction of knowledge both individually and collaboratively.

Questions are one of the psychological tools for thinking, and when embedded in the discourse of collaborative peer groups, help learners co-construct knowledge inter-psychologically. This knowledge is then appropriated or constructed intra-psychologically by the individual members (Vygotsky, 1978). From a social-cognitive perspective, questioning in a group context can also encourage students to reconsider their ideas in new ways because they are exposed to different peer perspectives. For example, Quin reconsidered his ideas of melting and evaporating in the activity on separating the salt-sand mixture after discussion with Carl and Rick. Question-generation is a constructive activity and is an essential component of student discourse in "talking science" (Hawkins & Pea 1987; Lemke, 1990) in the social construction of knowledge (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Relationship Between Nature of Students' Questions and Their Learning Approaches

The types of questions that students ask can reveal their depth of thinking. Wonderment questions are associated with a deep approach to learning whereas basic information questions are related to a more surface approach. Since asking wonderment questions is reflective of deep learning, teachers should encourage students to ask such questions and to "enter the depth dynamic" (Chin & Brown, 2000a) so as to increase their depth of thinking in other related areas. According to this "depth dynamic" model, the asking of wonderment questions can help learners initiate a process of hypothesizing, predicting, thought-experimenting, and explaining, thereby leading to a wave of generative activity. However, asking wonderment questions is indicative of only one dimension of a deep learning approach, the other possible dimensions being generative thinking, nature of explanations, metacognitive activity, and approach to tasks (Chin & Brown, 2000b).

Students asked mainly procedural questions when the assigned tasks required them to follow given instructions and step-by-step procedures, and this did not engage them at high cognitive levels. Such questions elicited only short, simple answers without leading to further conceptual talk, and students adopted a surface learning approach. In contrast, an open-ended, problem-solving activity carried out in the spirit of a scientific inquiry elicited a richer range of wonderment questions and talk at higher conceptual levels. This implies that the nature of tasks that teachers set and the cognitive demands required of the students influence the types of questions that students ask, and thus to some extent, the learning approach and learning strategies that they adopt. Hence, to encourage deep thinking in their students, teachers should present their laboratory activities in a way that encourages inquiry and problem-solving rather than following instructions to obtain an expected answer.

Asking wonderment questions can stimulate either the questioners themselves or other students to generate an answer, thereby bringing to the fore other deep learning strategies which have hitherto been latent, and potentially leading to talk at a higher conceptual level. One implication arising from this pertains to the assignment of students in groups. A teacher might consider including at least one “inquisitive” student in a group to steer other group members in their thinking and co-construction of knowledge.

Although the students did not always generate wonderment questions spontaneously, they asked more meaningful questions upon subsequent probing and nudging during the post-instructional interviews and when they were requested to write questions in their learning journals. This is evident in both the boiling point laboratory and chromatography activities when the students were able to pose such questions after carrying out the activities upon further encouragement by the author or teacher. This suggests that many students would not ask this kind of questions unless they are stimulated to think about such questions. Consequently, a lot of potential conceptual talk could be untapped if these questions are not asked. Teachers cannot simply rely on students’ spontaneous questioning and must explicitly orient their students toward asking questions, for example, by specifically encouraging them to generate questions, either verbally or written, as part of their class activities. Besides prompting students to think more deeply about what they are doing and encouraging critical thinking, such questions could also provide feedback to teachers about their students’ thinking and puzzlement.

Even the students who typically did not spontaneously ask higher-level wonderment questions were capable of asking thoughtful questions when time was specifically set aside for them to ask questions about things that puzzled them or which they were curious about. This suggests that teachers could explicitly encourage such students to ask questions by providing them extra opportunities to do so.

Strategies to Encourage Student Questioning

The findings of this study indicate that student-generated questions are an important aspect of learning in science as they can stimulate students to engage in thinking processes such as hypothesizing, predicting, and explaining. So how can teachers encourage a "question-based learning" approach (Watts, Gould, & Alsop, 1997) in their classrooms? Teachers could ask students to write their questions before performing an activity to help them direct their own inquiry and use these questions as a springboard for investigation and discussion. The students could also write questions as they are working on their tasks or at the end of the activity, regarding what had puzzled them, or what they want to know more about.

To foster a classroom discourse that promotes question-asking, teachers could provide students with suitable stimuli (Biddulph, Symington, & Osborne, 1986) such as a table of data or diagram (White & Gunstone, 1992) or anomalous happenings and materials that do unexpected things (Jelly, 1985). Students can also be taught to begin questions in a particular way (e.g., "What if …," "Why does …," "Why are …," and "How would …") as such questions are more likely to elicit deeper thinking than simple recall. Such thought-provoking question stems can help students generate questions that prompt them to compare and contrast, infer cause and effect, note strengths and weaknesses, evaluate ideas, explain, and justify (King, 1994). Students can also be guided to form investigable questions that are amenable to practical investigations. Such questions, which have been termed "productive" questions (Elstgeest, 1985) or "operational" questions (Alfke, 1974; Allison & Shrigley, 1986), help students manipulate variables in science experiments through eliminating, substituting, and increasing or decreasing the presence of a variable.

Teachers can ask their students to record their questions in a learning journal, thus documenting a set of "I wonder" questions (Kulas, 1995). Teachers can also pause at convenient intervals during the lesson and request the students to write down questions they wish to ask, and then use these questions as "thought provokers" for stimulating discussions (Maskill & Pedrosa de Jesus, 1997). Watts, Gould, and Alsop (1997) have also suggested including specific times for questions such as a period of "free question time" during lessons, a question "brainstorm" at the start of a topic, a "question box" on a side table where students can put their questions, turn-taking questioning around the class where each student or group of students must prepare a question to be asked of others, and "question-making" homework. Teachers can also establish a "problem corner" in the classroom and encourage students to supply "questions of the week" (Jelly, 1985).

It is common knowledge among educators that to know how to question is essential to knowing how to teach well. However, given the current emphasis on critical thinking, inquiry, and student-centred learning, we should also impress upon our students that to know how to question is also to know how to learn well.

References

Alfke, D. (1974). Asking operational questions. *Science and Children*, *11*(7), 18–19.

Allison, A. W., & Shrigley, R. L. (1986). Teaching children to ask operational questions in science. *Science Education*, *70*(1), 73–80.

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

Bogdan, R. C., & Biklen, S. K. (1992). *Qualitative Research for Education: An Introduction to theory and methods* (2nd ed.). Boston: Allyn & Bacon.

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

Chin, C., & Brown, D. E. (2000a). Learning deeply in science: An analysis and reintegration of deep approaches in two case studies of grade 8 students. *Research in Science Education*, *30*(2), 173–197.

Chin, C., & Brown, D. E. (2000b). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching*, *37*(2), 109–138.

Chin, C., Brown, D. E., & Bruce, B. C. (in press). Student-generated questions: A meaningful aspect of learning in science. *International Journal of Science Education*.

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

Donaldson, M. (1978). *Children's minds*. London: Croom Helm.

Dori, Y. J., & Herscovitz, O. (1999). Question-posing capability as an alternative evaluation method: Analysis of an environmental case study. *Journal of Research in Science Teaching*, *36*(4), 411–430.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, *23*(7), 5–12.

Elstgeest, J. (1985). The right question at the right time. In W. Harlen (Ed.), *Primary science: Taking the plunge* (pp. 36–46). London: Heinemann.
Entwistle, N. J., & Ramsden, P. (1983). *Understanding student learning*. London: Croom Helm; New York: Nichols.
Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine.
Hawkins, J., & Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching*, *24*(4), 291–307.
Jelly, S. (1985). Helping children raise questions — and answering them. In W. Harlen (Ed.), *Primary science: Taking the plunge* (pp. 47–57). London: Heinemann.
Keys, C. W. (1998). A study of grade six students generating questions and plans for open-ended science investigations. *Research in Science Education*, *28*(3), 301–316.
King, A. (1994). Guiding knowledge construction in the classroom: Effects of teaching children how to question and how to explain. *American Educational Research Journal*, *31*(2), 358–368.
Koch, A., & Eckstein, S. G. (1991). Improvement of reading comprehension of physics texts by students' question formulation. *International Journal of Science Education*, *13*(4), 473–486.
Kulas, L. L. (1995). I wonder …. *Science and Children*, *32*(4), 16–18.
Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex.
Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA: Sage.
Maskill, R., & Pedrosa de Jesus, H. (1997). Pupils' questions, alternative frameworks and the design of science teaching. *International Journal of Science Education*, *19*(7), 781–799.
Merriam, S. B. (1988). *Case study research in education: A qualitative approach*. San Francisco: Jossey-Bass.
Olsher, G., & Dreyfus, A. (1999). Biotechnologies as a context for enhancing junior high-school students' ability to ask meaningful questions about abstract biological processes. *International Journal of Science Education*, *21*(2), 137–153.
Osborne, R. J., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education*, *67*(4), 489–508.
Osborne, R., & Wittrock, M. (1985). The generative learning model and its implications for science education. *Studies in Science Education*, *12*, 59–87.
Pearson, J. A. (1991). Testing the ecological validity of teacher-provided versus student-generated postquestions in reading college science text. *Journal of Research in Science Teaching*, *28*(6), 485–504.
Pizzini, E. L., & Shepardson, D. P. (1991). Student questioning in the presence of the teacher during problem solving in science. *School Science and Mathematics*, *91*(8), 348–352.

Scardamalia, M., & Bereiter, C. (1992). Text-based and knowledge-based questioning by children. *Cognition and Instruction*, *9*(3), 177–199.

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Tisher, R. P. (1977). Practical insights gained from Australian research on teaching. *Australian Science Teachers Journal*, *23*(2), 99–104.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Watts, M., & Alsop, S. (1995). Questioning and conceptual understanding: The quality of pupils' questions in science. *School Science Review*, *76*(277), 91–95.

Watts, M., Gould, G., & Alsop, S. (1997). Questions of understanding: Categorising pupils' questions in science. *School Science Review, 79*(286), 57–63.

White, R. T., & Gunstone, R. F. (1992). *Probing understanding*. London; New York: Falmer Press.

Wong, B. Y. L. (1985). Self-questioning instructional research: A review. *Review of Educational Research*, *55*(2), 227–268.

Woodward, C. (1992). Raising and answering questions in primary science: Some considerations. *Evaluation and Research in Education*, *6*(2&3), 145–153.

Zoller, U. (1987). The fostering of question-asking capability: A meaningful aspect of problemsolving in chemistry. *Journal of Chemical Education*, *64*(6), 510–512.