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Student-Generated Questions: Encouraging Inquisitive Minds in Learning Science

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The imitative student, if given a question, will answer it.
The creative student, if given an answer, will question it.

(Edgar Dale)

In a typical classroom setting, the teacher presents information and poses questions to which students answer. Rarely do students ask questions to which the teacher responds. Given this state of affairs, it is difficult for the teacher to know the kinds of puzzlement that students have if their questions are not articulated. More importantly, questions are also psychological tools for thinking as they help to scaffold ideas, and can advance students' understanding of scientific concepts and phenomena. The act of asking questions and the consequent search for answers is key to active learning. The formulation of a good question is also a creative act, and at the heart of what doing science is all about. Hence, students should be encouraged to ask questions as this facilitates learning. The purpose of this paper is to highlight the value of students' questions in the learning-teaching process, review the research on student-generated questions in science learning, suggest some strategies that teachers can use to foster a 'culture of inquisitiveness' in their classrooms, and discuss some related issues and implications of students' questions for science teaching.

The Value of Students' Questions

Questioning is an integral part of meaningful learning and scientific inquiry. The value of student-generated questions in science learning has been emphasized by authors such as Biddulph, Symington, and Osborne (1986) and White and Gunstone (1992). Students' questions can serve different functions such as confirmation of

an expectation, resolution of an unexpected puzzle, and filling a recognized knowledge gap (Biddulph and Osborne, 1982). Student questioning, particularly at the higher cognitive levels, is also an essential aspect of problem-solving (Pizzini & Shepardson, 1991; Zoller, 1987). The source of questions is a gap or discrepancy in the students' knowledge or a desire to extend knowledge in some direction. Questions may occur spontaneously or in response to stimulation.

Besides helping students learn, student questioning can also guide teachers in their work. Questions indicate that students have been thinking about the ideas presented and have been trying to extend and link them with other things they know. They can also reveal much about the quality of students' thinking and conceptual understanding (Watts, Gould, and Alsop, 1997; White and Gunstone, 1992), their alternative frameworks and confusion about various concepts (Maskill and Pedrosa de Jesus, 1997), their reasoning, and what they want to know (Elstgeest, 1985).

A hallmark of self-directed, reflective learners is their ability to ask themselves questions that help direct their learning. These questions could be those pertaining to the science content of interest, or evaluative questions that help the learners monitor the status of their understanding. Self-questioning provides learners with a way to test themselves, to help them check how well they are comprehending what they are studying. It is a source of feedback that helps students redirect their use of learning strategies. Thus, the effectiveness of self-questioning is attributed to both its cognitive and metacognitive functions. Self-questioning is also consistent with the view of generative learning (Osborne and Wittrock, 1985) as learners try to reconcile their prior knowledge and new information in their attempts to make sense of these ideas.

How does question-asking facilitate knowledge construction? Questions, particularly those asked in response to wonderment, stimulate students to generate explanations for things which puzzle them and to propose solutions to problems. These questions trigger the use of deep thinking strategies which may not be invoked if the questions had not been asked, and thus they play an important role in engaging students' minds more actively. Such questions can help learners initiate a process of hypothesizing, predicting, thought experimenting, and explaining, thereby leading to a cascade of generative activity, and help them acquire missing pieces of knowledge or resolve conflicts in their understanding (Chin and Brown, 2000). When students engage socially in talk and activity about shared problems or tasks, an individual's questions can also stimulate another group member to use these strategies and thinking processes. The questions embedded in the discourse of peer groups help learners co-construct knowledge during the dialogic and dialectic process.

Question production, particularly of 'thinking' or more probing questions, is not a usual student role. Consequently, in classroom situations, students are more often expected to answer questions rather than to ask them. Few students spontaneously ask high quality thinking questions (White and Gunstone, 1992, p. 170).

The number and type of questions that students ask may be influenced by their age, experiences, prior knowledge and skills, the attitude of the teacher, teaching style, nature of the topics, reward structure, classroom evaluative climate, and social interaction patterns (Biddulph and Osborne, 1982). Furthermore, interesting and productive answers are dependent upon being able to first come up with good questions for eliciting them (Shodell, 1995). Low levels of questioning and explanation on the part of students have been found to be correlated with lower achievement (Tisher, 1977).

Research on Student-Generated Questions

Watts and Alsop (1995) found that students' questions were indicative of the routes through which students were seeking understanding. In particular, consolidation questions, exploration questions, and elaboration questions illuminated distinct periods in the process of conceptual change. Keys (1998) found that in the context of open-ended science investigations, students' questions determined the depth and breadth of the concepts to be learnt, the scientific processes to be used, and the cognitive difficulty of the investigative tasks. Allowing students to generate their own investigative 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 had about problems or difficulties they were encountering. Students' questions were found to be a good source of information about each specific moment of the lesson and provided the teacher with a great deal of information with which to organise future teaching according to students' needs. The findings by Dori and Herscovitz (1999) indicate that students' question-posing capability can be used as a means of evaluating higher-order thinking, and suggests the potential of question-posing as a viable evaluation tool that offers an alternative to conventional evaluation methods.

The study by Chin, Brown, and Bruce (in press) identified the types of questions that students asked during science learning, and investigated the role of these questions in the knowledge construction process, as well as the relationship between students' questions and their approaches to learning. Students' questions included basic information (factual and procedural) questions which were typical of a surface learning approach, and wonderment (comprehension, prediction, anomaly detection, application, and planning) questions which were indicative of a deep approach. Unlike wonderment questions which stimulated the students to hypothesize, predict, thought-experiment and generate explanations, basic information questions generated little productive discussion. Problem-solving activities elicited more and a wider range of wonderment questions than teacher-directed activities. Although the students did not always ask wonderment questions spontaneously, they were able to generate such questions when prompted to do so.

The above review indicates that there is substantial educational potential in student-generated questions in directing students' learning and guiding their construction of knowledge. Students' questions, particularly those posed at a higher cognitive level, can promote conceptual talk that pertain to important concepts, thereby leading to enhanced learning. In addition to bringing about more meaningful learning on the part of the students, these questions can also provide useful information and feedback for the teacher about students' thinking, puzzlement, and the status of their understanding, and thus act as a window to the students' minds.

Fostering Students' Questions

Given the important role of student-generated questions in the learning process, what can teachers do to foster a 'culture of inquisitiveness' in science classrooms? What specific, practical strategies can teachers adopt to encourage student questioning?

To promote a classroom discourse that stimulates question-asking as well as higher level cognitive and metacognitive talk, the teacher 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. For example, before carrying out a chromatography activity involving different coloured marker pens, students might ask "What is the purpose of this activity?". The students could also think about particular questions as they work on their tasks. An example of such a question might be "How would I interpret the pattern of spots on the chromatogram?". Then, at the end of the activity, the students can write questions reflecting what they wondered about, what had puzzled them, or what they needed to know to understand more about the topic in question. A possible question would be "What are the applications of chromatography in everyday life?". Through this process of question-asking and explaining, the students verbalize their ideas, reflect on the thinking they have engaged in, and externalise mental activities that are usually covert.

It is not enough merely to provide opportunities for students to ask questions. Teachers need to take a proactive stance and employ strategies to encourage students to ask questions. Biddulph, Symington, and Osborne (1986) suggested four ways of doing this. These include providing students with suitable stimuli, modelling question-asking, developing a receptive classroom atmosphere, and including question-asking in evaluation. To provide students with suitable stimulus material, Jelly (1985) proposed that teachers use anomalous happenings and materials that do unexpected things as question stimulators, and that students be put in contact with interesting materials and given the opportunity to ask questions. Symington (1980) has also reported that letting students enjoy a period of unstructured observation with materials increased the number of questions they were able to ask. Students need to have some

basis on which to generate questions; otherwise, they have little idea of what questions to ask.

White & Gunstone (1992) proposed the use of structuring or focusing strategies such as providing a stimulus (e.g. table of data or diagram) on which questions are to be based, providing an answer and asking for questions, and asking students to begin questions in a particular way (e.g. 'What if ...', 'Why does...', 'Why are ...', 'How would ...') as such questions are more likely to be based on deeper thinking than simple recall. Students may need to be shown how to form questions. Modelling question-asking by the teacher is one way of doing this. White (1977) has suggested that the ability to formulate questions is a skill which needs to be taught rather than left to chance, and that the teacher could provide examples of how to form questions. For instance, the teacher can show a picture of an object or event, say the heating of water, and after saying 'What questions can we think of about this?', starts giving examples such as 'At what temperature do the bubbles begin to form?', 'What are the bubbles made of?', and 'How high can the temperature go up to as the water continues to boil?'. Subsequently, the teacher can simply present the picture and call for questions.

Students may also need explicit training in questioning strategies such as learning the linguistic forms of effective queries and the syntax of question formulation. King (1994) found that giving students thought-provoking question stems such as 'What is the difference between ... and ...?', 'How does ... affect ...?', and 'What are the strengths and weaknesses of ...?' helped them to generate questions that prompted them to compare and contrast, infer cause and effect, note strengths and weaknesses, evaluate ideas, explain, and justify.

Students can also be guided to form investigible questions that are amenable to practical investigations. Such questions have been termed 'productive' questions (Elstgeest, 1985) or 'operational' questions (Alfke, 1974; Allison and Shrigley, 1986). Operational questions help students to manipulate variables in science experiments through eliminating, substituting, and increasing or decreasing the presence of a variable. Examples of such questions related to the dissolution of sugar in water would be 'How would the rate of dissolving change if we (a) do not stir the sugar-water mixture, (b) use brown sugar instead of white sugar, and (c) increase / decrease the temperature of the water?'.

To foster a question rich environment, White (1977) has suggested that 'praise should be given to those who invent questions, repressions should be avoided' (p. 125). Students would feel comfortable with asking questions only when they have no fear of censure, criticism, or ridicule, and when their questions are valued, no matter how silly they seem to be. Students' questions must always be received with sensitivity and enthusiasm. Several authors (Eisner, 1965; White & Gunstone, 1992) have also suggested that teachers ask students to write questions about aspects of what they are learning which are puzzling to them. Teachers can also ask their students to record any questions that they have in a diary or learning journal, thus documenting a set of 'I Wonder' questions (e.g. Kulas, 1995). The teacher can

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).

Dixon (1996) described the use of a 'question board' to display students' questions relating to the topic being taught and described how these questions may be used as starting points for scientific investigations. Such a board can encourage less vocal students to put forward their questions. Students can find out the answers to the questions by looking in books, asking someone, or carrying out investigations themselves to answer their questions. Watts, Gould, & Alsop (1997) have also suggested including specific times for questions such as a period of 'free question time' within a lesson or block of lessons, a question 'brainstorm' at the start of a topic, a 'question box' on a side table where students can put their (anonymous) 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).

Some Issues and Implications of Students' Questions for Science Teaching

When teachers encourage students to ask questions, there are a number of issues which they need to be cognizant of. First, 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. When the assigned tasks simply require students to follow given instructions and step-by-step procedures, this does not engage students at high cognitive levels, and they would ask mainly procedural and factual questions. Learning in such a context encourages students to make sure they do things right, according to the teacher's expectations. In contrast, an open-ended, problem-solving activity would elicit more and a richer range of wonderment questions and talk at higher conceptual levels.

Second, when students work in groups, asking wonderment questions can stimulate either the questioners themselves or another student to generate an answer, thereby potentially leading to talk at a high conceptual level. Some students are also more inclined than others to ask questions. One implication arising from this pertains to the assignment of students in groups. Would grouping a more 'inquisitive' student with other members who question less, help to steer the other members in their thinking and co-construction of knowledge? Or might this student dominate the group and hinder the others from asking questions instead? These are questions that have no clear-cut answers, and the outcome might depend on the particular group of students involved. The teacher could explore this issue with groups of students to find out the optimum grouping that would lead to productive discourse.

Third, students do not always ask wonderment questions spontaneously, perhaps because they may not even be aware of what they do not know or understand. Unless they are stimulated to think about such questions, many would not ask them. Students also do not necessarily say if they have problems or doubts, maybe because they are too shy to express themselves. Thus, many of their questions and puzzlement may go undetected and not be dealt with as the teacher may not be aware of them. Consequently, much potential conceptual talk could be untapped if these questions are not asked. This implies that teachers cannot fully rely on students' spontaneous questioning and must explicitly orientate their students towards asking questions, for example, by specifically encouraging them to generate questions, either verbally or written, as part of their class activities.

Fourth, even students who typically do not spontaneously ask higher-level wonderment questions are capable of asking thoughtful questions when time is specifically set aside for them to ask questions about things that puzzle them or which they would like to know more about. This implies that teachers could explicitly encourage such students to ask questions by providing extra opportunities for them to do so.

Fifth, teachers may sometimes feel uncomfortable with the idea of encouraging students to ask questions because they may not know all the answers to the questions. In such situations, it is important for students to know that it is not always possible for the teacher to know all the answers. The teacher can guide the students to search for answers from books or the internet, consult an expert, or even have the students carry out their own investigations to obtain first-hand information and answer the question themselves. It is, however, important that students' questions be addressed in one way or another; otherwise students would feel that they are asking questions simply for the sake of asking them, and may gradually lose interest in posing questions if they are not responded to.

Epilogue

As educators, we know that the skill in the art of questioning is essential to teaching well. However, with the emphasis today on active learning, critical and creative thinking, skill in the art of questioning is also critical to learning well.

When Isidore Rabi, Nobel prize-winner in physics was asked what had helped him become a scientist, he was reported to have said:

> Every other Jewish mother in Brooklyn would ask her child after school: 'So, what did you learn in school today?'. But not my mother. 'Izzy,' she would say, 'did you ask a good question today?'

That difference — asking good questions — was what made him become a scientist, the Nobel laureate maintained.

If we were to challenge our students to ask a 'good question' daily, perhaps they too would grow up within a culture of inquisitiveness. This would be a bold but worthwhile step to take.

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