By
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Questioning Students in ways that encourage thinking

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One objective of biology teaching is to help students become critical thinkers and independent, creative problem solvers. To achieve this, we need to stimulate students' thinking by requiring them to go beyond the factual recall or procedural levels, and to engage in higher order thinking which involves the application, synthesis, and evaluation of knowledge. One way of doing this is through the art of skilful teacher questioning. This article reviews the literature on teacher questioning and discusses how teachers can use oral questioning strategies to foster deeper thinking in their students when teaching biology.

Introduction

The kinds of questions that teachers verbally ask during instruction can, to some extent, influence the type and level of thinking operations that students engage in. To help students think more critically and creatively beyond mere recall, teachers can sharpen their questioning skills by becoming familiar with different types of questions, and then practise using them. This article describes different categories of teacher questions, suggests tips for effective questioning, and provides examples to illustrate these ideas.

Categories of Teachers' Questions

Bloom's Taxonomy

One category of questions classified according to different *cognitive levels* is Bloom's (1956) taxonomy. Ranging from lower to higher levels of thinking, these include knowledge, comprehension, application, analysis, synthesis, and evaluation. Table 1 gives examples of such questions. [see below]

Open and Closed Questions

Blosser (1995) referred to the use of closed and open questions. *Closed* questions have a limited number of acceptable responses or 'right answers', and can be further divided into *cognitive memory* or convergent types. Cognitive memory questions are of a lower order and focus on factual recall. An example is 'What is the chemical formula for glucose?'. *Convergent* questions, while leading to a limited number of acceptable answers, need not always be pitched at lower levels of thinking. They can require students to:

- compare and contrast (e.g. 'Based on your observations in today's laboratory activity, what are the differences between the cross-sectional structure of a monocotyledonous and a dicotyledonous stem?')
- apply previously learned information to a new problem (e.g. 'Why is it recommended that we use low temperatures (<45 oC) when using biological washing powders to remove egg and gravy stains from clothes?')
- make a judgment (e.g. 'If you are scuba diving at 20m below sea level and have only one minute of oxygen left, would you surface at the fastest possible rate of 20m per minute, or more slowly if you can hold your breath for 3 minutes?').

Open questions elicit a wide range of possible responses rather than one or two 'right answers', and often have the potential to stimulate higher level

Table 1 Questions classified according to Bloom's Taxonomy

Question Type	*Example of Question*
Knowledge	• Which organs in the human alimentary canal produce enzymes that digest proteins?
Comprehension	• What does this graph tell you about how temperature affects enzyme activity?
Application	• Why does the liver store glycogen and not glucose?
Analysis	• What are the pros and cons of storing celery in the refrigerator compared to preserving it in salt or vinegar?
Synthesis	• How would you create a meal plan for a pregnant woman so that it meets her daily needs?
Evaluation	• Which of these three meal plans (A, B, or C) would you recommend to a person who has diabetes and high blood pressure? What are the reasons for your choice?

thinking. They promote discussion and encourage students to hypothesize, speculate, invent possibilities, interpret, and share ideas. They require students to give and justify their opinions, infer or identify implications, and to make judgments based on their own values and standards. They may be further subdivided into divergent or evaluative thinking questions. An example of a *divergent thinking* question is 'What do you think life on Earth might be like if the proportions of gases in the atmosphere were different?', while an *evaluative thinking* question might be 'What is the best way to depict the results of this experiment - by using just words, a drawing, table, line graph, bar chart, or ....?'.

Productive Questions

Elstgeest's (1985) guide to questioning focuses on 'productive' questions which include attention-focusing, measuring, comparison, action, problem-posing, and reasoning questions. This sequence of productive questions may be seen as proceeding systematically from concrete to abstract (Anderson, 1999). These questions stimulate *productive* physical or mental activity and reasoning in students, and take them forward in their thinking. They provide scaffolding for students to construct their own understanding. On the other hand, 'unproductive' questions do not encourage learning; instead, they require wordy answers, often neatly dressed in bookish phrases.

Attention-focusing questions guide the initial exploration of new materials and direct students' attention to significant details that they might overlook. An example is 'During the germination of a seed, does the radicle or plumule emerge first?'. *Measuring* questions nudge students to move from purely qualitative to quantitative ideas, and to strive for greater precision in their observations and measures. For instance, in the design of an experiment on the fermentation of sugar by yeast, the teacher could ask 'How would you measure the amount of gas evolved in this reaction?'. *Comparison* questions encourage sharper observation and help students 'bring order into chaos and unity in variety' (Elstgeest, 1985, p. 38). An example is 'What do you notice about the differences in structure between wind-pollinated flowers and insect-pollinated flowers?'.

Action questions ask 'What happens if....?' and encourage simple hands-on experimentation and the investigation of relationships. They challenge students to predict the outcome. An example would be 'What would happen to the rate of photosynthesis if the light intensity is increased?'. *Problem-posing* questions of the 'Can you find a way to ....?' type set up a real problem-solving situation that invites students to predict, hypothesize, identify and control variables, and plan and conduct experiments. They require students to integrate and apply their knowledge in new and creative ways. A question such as 'Given these three unknown suspensions, how would you find out whether they contain sugar, starch, protein, or fats?' would be of this type. Elstgeest (1985) advised teachers to ask reasoning questions, such as those beginning with 'why', with discretion. These questions are intended to make students think and reason, search for cause-effect relationships among variables, and postulate theories. However, because they often ask for some sort of explanation, anxious students may mistake them for test questions and be afraid of being 'wrong', especially if they feel that there is only one right answer. If the content is pitched beyond a student's ability and experience, these questions often cannot be answered by anything other than the recall level. If asked prematurely, asking why something occurs may be too difficult for students, as the answer often involves some mechanism that is explained by theorizing at an abstract level. An example is 'Why is the rate of photosynthesis higher when blue light instead of yellow light is used?'. The reasons given by students themselves based on their own reasoning, evidence, and experiences are more important than impressive sounding answers, faultlessly recited without understanding. Care is needed in how these questions are phrased and in when they are presented. A question phrased as 'Why, *do you think* ....?' sounds less intimidating than 'Why ....?' as the student's ideas and thinking, and not an authoritative answer, is sought. Also, ask these questions only when students have had the necessary experience and knowledge to reason from evidence and construct sensible arguments.

Operational Questions

Alfke's (1974) questioning model is an elegant but simple means of helping students identify, control, and manipulate variables in science experiments. It systematically directs the teacher and student to investigate science phenomena through the use of *operational* questions which manipulate variables through: (a) elimination, (b) substitution, and (c) increasing or decreasing the presence of the variable. The questions lead to a task by which the student can arrive at answers by working hands-on with materials and obtaining first-hand evidence. For example, when investigating the enzyme activity of pepsin on egg albumen, such questions might include: 'What would happen if the few drops of dilute hydrochloric acid are not added?' (elimination), 'What if we use rennin instead of pepsin?' (substitution), and 'How would the rate of reaction be affected if we use a higher / lower temperature?' (increasing / decreasing variable).

Non-operational questions are those that cannot be easily answered by first-hand experimentation and are more abstract, requiring theoretical answers or the use of conceptual models. They include: 'Why does amylase act only on starch and not on proteins or fats?'. However, a question such as 'How does a change in pH affect the activity of amylase on starch?' would be operational. Allison and Shrigley (1986) found that when teachers modelled the asking of operational questions, their students also asked more of such questions during their science demonstrations. Since variable identification and manipulation are central to much of the cause-effect relationships in scientific inquiry, operational questions are a means of encouraging students to think about such relationships.

Questions for Creative Thinking

Gilbert (1992) described a taxonomy for questions in the domain of creativity. He referred to the categories of association, imagination, brainstorming, organisation, analogy and metaphor, and reconceptualisation. Possible questions falling into these categories in teaching biology include 'What do you think of when I say the word "protein"?' *(association)*, 'What do you think you would see in the cell nucleus if you saw it through magic magnifying glasses?' *(imagination)*, 'What factors might affect the rate of transpiration in plants?' *(brainstorming)*, 'In what different ways might you classify these flowers?' (organisation), 'How is the leaf like a food-making factory?' *(analogy and metaphor)*, and 'If matter is energy, what does that make us?' *(reconceptualisation)*.

Some Research Findings on Teacher Questions

Carr (1998) conducted a paired observation exercise where science teachers paired up to observe each other's lessons on class questioning and compare notes. Some types of questions asked included (a) *open* questions, (b) *probing* questions, which are asked to obtain more detailed and specific information, (c) *reflective* questions, which are used to crystallise a particular point (e.g. 'But what if this happened?'), (d) *closed* questions, and (e) *hypothetical* questions, which pose a situation for the student and are very useful in teaching investigative skills.

The above study found that open questions were not asked as frequently as closed questions. Closed questions were used during review to consolidate information and to keep straying students on track. It was also found that questions coupled with ad hoc diagrams and illustrations were a richer learning experience and were more effective at prompting student involvement, questions and answers. When students were asked multiple questions coming in pairs or threes before they had a chance to respond, it was confusing and unhelpful to their thinking and learning. The teachers also thought that they had to focus on asking more open questions as their students needed to be given the opportunity and scope to develop extended answers and to learn, by doing so, to structure their thinking.

Koufetta-Menicou and Scaife (2000) classified science teachers' questions into nine categories, according to the mental operation required for each of them to be answered. The two categories of lower level thinking questions asked for (a) recall of facts, events, and definitions, and (b) *descriptions* of a situation and the identification of variables. Higher

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level questions included (c) those that basically begin with *how* and ask for a description and justification of procedures (e.g. 'How did you test whether ....'), (d) those that seek *proof* or evidence (e.g. 'What evidence have you got for that?'), (e) those that recognise a *pattern* or describe the trend in a graph, (f) those that begin with *why* and ask for a *reason* behind the procedure followed (e.g. 'Why is this fair?'), (g) *what-if* questions that ask students to hypothesize (e.g. 'What would be the problem if ....?'), (h) *prediction* questions, and (i) *conclusion* questions that require students to reframe information (e.g. 'What did we learn about the ....?').

The above authors found that questions which require lower level mental operations (categories a and b) were not positively related to any kind of desired learning outcome. The implication is that this type of question 'makes very little contribution to the quality of teaching' and that 'unless a teacher offers students appropriate experiences in categories beyond the recalling/memory one, teaching cannot be assumed to be effective in developing higher level thinking' (Koufetta-Menicou and Scaife, pp. 82-83). Also, 'how' questions (category c) appeared to be associated with students' use of metacognitive skills. Requiring students to think not only about the 'how' (procedure) of a particular setting, but also the underlying reasons, was an important step towards metacognition. Furthermore, questions seeking evidence (category d) were strongly associated with teachers' guidance towards appropriate resolution of cognitive conflicts. This may be because the resolution of cognitive conflicts depends on giving explanations and constructing scientific arguments, which is in turn linked to the identification of evidence. The findings also suggested that 'asking more questions ... does not guarantee higher level learning' and that 'it is the types of questions that matter and not simply their quantity' (p. 83).

Stimulating Deeper Thinking Through Teacher Questioning

An emphasis on lower order or recall questions encourages students to memorise information. To promote deeper and more reflective thinking in our students, we should also include higher order questions as part of classroom discourse. The following are some suggestions to foster thinking through our questions:

1. ***Familiarise yourself with the levels of thinking elicited by different types of questions.***

To ask higher order thinking questions, you must first be familiar with the level of thinking invoked by the various types of questions, as discussed above. You can use one or more of the above-mentioned question categories to generate your questions, remembering to establish a balance between questions of different degrees of complexity. This will also ensure that you ask a diversity of question types.

2. ***Identify the cognitive skills and processes that you would like your students to engage in, and then craft the question to elicit the desired kind of thinking.***

Ask yourself if your questions require students to (a) recall facts and procedures that they have come across before, (b) explain an event or phenomenon, (c) infer from patterns, trends, or underlying relationships in data, (d) predict outcomes, (e) evaluate and use criteria to make a judgment about some given information, (f) formulate alternative hypotheses for the same observations, (g) plan and design an experiment to test something that they would like to investigate, or (h) propose and generate solutions to a problem, especially one where the problem is embedded in a real world context and the solution is non-stereotypical, yet feasible.

Questions that require students to engage in thinking at the recall level as in (a) above (e.g. 'What enzyme used in making cheese is responsible for coagulating the casein?') would be of a lower order. Those that expect students to give explanations as in (b) encourage them to apply their understanding of concepts to a new situation, provided that the explanations have not been rote learnt or rehearsed before (e.g. 'Why are yoghurt and cheese, which are products of microbial activities, more resistant to spoilage than the milk from which they are made?'). When students are asked to infer (e.g. 'Based on the results of this experiment, what do you think is the water potential of the potato tissue?'), predict (e.g. 'What would happen to the rate of browning if I immerse the cut apple slices in vinegar?'), and evaluate (e.g. 'What are the advantages and disadvantages of using an artificial kidney machine compared to getting a kidney transplant?') as in (c) through (e) above, such questions are pitched at the critical thinking level and are of a higher order. If the questions demand students to suggest alternative hypotheses (e.g. 'What might be some possible reasons why ....?') as in (f), design an investigation or generate solutions to a problem in a new situation (e.g. 'How would you help a florist, in the most efficient and economical way, to increase the range of colours of flowers to be displayed at her shop and that would stay fresh for as long as possible?') as in (g) and (h), they invoke creative thinking on the part of the students.

Simple enhancements in crafting a question can turn it from a recall or an algorithmic exercise to a real problem. Consider the question 'What factors affect the rate of photosynthesis in a plant?'. To answer this question requires little thinking beyond simple recall. We can stimulate deeper thinking in students by omitting information, requiring assumptions, or including superfluous but seemingly relevant information. Context-rich problems that present real-world situations where the key variables, concepts, and essential information must be identified by students can also be used. Consider the question 'What advice would you give a farmer entering an agricultural contest who wants to ensure that his lettuce would grow at the maximum rate possible and produce the largest heads with plenty of leaves?'. For such a question, students need to consider not only the factors influencing photosynthesis, but also other related concepts such as mineral nutrition, plant growth substances, environmental conditions, and genetics. Such a question promotes discussion of what assumptions must be made, what must be done and how to do it, and will help students develop critical thinking and problem solving skills.

3. *Use Wait Time.*

After asking a question, teachers are often anxious for an immediate response. If none is forthcoming, they may answer their very own questions themselves. You need to pause or build in wait time of about three to five seconds for students to formulate reasoned responses, particularly for higher order questions. Rowe (1987) reported that when science teachers extended their wait time to three seconds or more, the length of student responses, the incidence of speculative thinking, and the number of unsolicited but appropriate responses, inferences, students' questions, and contributions by slow learners all increased. Tobin (1987) also reported similar findings and higher levels of student achievement with extended wait time. In addition, he also found that teachers who increased their wait time asked fewer lower order questions but more probing and application questions.

4. *Provide a warm and conducive learning environment.*

It takes courage to venture a response to an open question publicly among peers. Sometimes students are not comfortable with risk-taking and would thus refrain from responding to the teacher's questions. They may be afraid of losing face or be laughed at by their classmates if they give an incorrect answer. A warm classroom climate with a low risk of censure, criticism, or ridicule is essential for promoting thinking via teacher questioning. If teachers are intolerant of 'wrong' or 'stupid' answers, students will be less forthcoming with their ideas, fearing that they may be dismissed as silly or 'rubbish'.
Teachers who believe in the virtue of divergent thinking will not be afraid to let their students make mistakes and turn those mistakes to good use, as building blocks in their search for understanding and workable solutions. Also, remember that your questions should be asked more in the spirit of an inquiry rather than an inquisition.

5. *Pay attention to the wording of your questions and responses.*

A question such as 'Would you get a yellowish-brown or dark blue stain if you spilt some iodine solution onto your writing paper?' limits your students to respond with 'yellowish-brown' or 'dark blue' or 'I don't know.' However, asking 'What would you observe if you spilt some iodine solution onto your writing paper?' requires students to apply what they have learnt, and think about why the stain would be of a different colour from the original solution. Try to phrase your questions to avoid 'yes' or 'no' answers, unless that is what you really want. Compare 'What do you think will happen to the plant if you omit magnesium from the plant culture solution?' with 'Do you think there will be a yellowing of leaves in a plant if you omit magnesium from the plant culture solution?'. The former requires the students to think through much more about mineral nutrition in plants and the role that magnesium plays in chlorophyll formation, while the latter encourages a simple 'yes/no' response.
Ask questions that are process-oriented, seek explanations, ask for evaluations, or stimulate imagination. Place emphasis on 'how', 'why', and 'what if', and on links to previous information. Use open questions to stimulate critical and creative thinking.
The following example illustrates the different types of teacher questions and responses that can inhibit or promote thinking in students.
Consider the following possible teacher responses to a student's incorrect prediction about the relative sizes of the cells at the root tips or shoot tips of a plant relative to the other parts: 'The cells at the tips need to grow more so they would be larger'. Teacher A who responds with 'That's not quite right. Would someone else like to try?' terminates the interaction with the student and thereby unintentionally suppresses the student's further cognitive processing. Compare this with Teacher B who responds with 'The cells at the root tips or shoot tips are actively dividing, so their metabolic rate is higher. What happens to the rate of intake of food and oxygen per unit mass of protoplasm? ...[Pause]... How is this related to the surface area to volume ratio of the cell? Would you like to try again?'. This teacher paraphrases the student's ideas and encourages the student to re-think and decide if that is indeed what he or she meant, helps the student to reflect on the earlier response, and find and correct his or her own mistake.

6. *Look for questioning opportunities in each and every lesson.*

Purposefully ask questions at strategic intervals throughout your lesson.
Plan the questions so that they fit in with the natural flow of the lesson, coordinating questioning towards particular directions. Questions requiring thinking beyond the recall level make excellent introductions, bridges, and trigger activities, and can arouse students' curiosity and motivation. Some useful sources for developing open questions include newspaper and magazine articles, short problem situations, and anecdotes from real-life experiences.

Identifying And Improving Your Questioning Skills

To find out your questioning practices, you can tape-record your lesson or a 'typical segment' of it, listen to yourself and your students' responses, and then analyse the questions that you asked. Analyse the number of possible and acceptable responses, and check the level of thinking that the questions stimulate. Also, ask yourself whether the questions require your students to go beyond recalling information in formulating a response. You can also analyse the way you phrase your questions. Words such as who, what, when, where, name, and sometimes how and why are often indicative of closed questions (Blosser, 1973). Words such as discuss, interpret, explain, evaluate, compare, if, and what if may elicit more than the retrieval of memorised information. However, they may also require only memory operations if the questions focus only on information from a previous lesson.

If you find that there is a lot of information-giving and a paucity of questions in your 'teacher talk', you could punctuate your exposition with questions. If you find that your questions are often pitched at the factual recall level and do not sufficiently stretch your students' minds, you may try asking a wider variety of questions to tap on students' higher level thinking processes. On the other hand, if you find that you are asking questions that are well above the heads of most students and are not getting any satisfactory responses, you may wish to ask more basic questions first and then follow up with more difficult ones progressively. Too many higher order questions can be frustrating for students and detrimental to the inquiry process. Lower order questions are helpful in reviewing basic concepts and can lay the foundation for meaningful discussions. By consciously asking questions that elicit the use of a variety of cognitive skills and processes, we can foster critical and creative thinking in our students. As Edward de Bono has so aptly put it, 'Asking a question is the simplest way of focusing thinking .... Asking the right question may be the most important part of thinking.'

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Science research - benefits for society.

By Anne Langsford

Your assignment

- Collect two articles of scientific importance from a current newspaper, a scientific magazine or a web site with scientific news.
- Cut out, copy, or provide the web address of your articles. Make sure you include the date and source of articles taken from magazines or newspaper.
- Compare the two articles, including the value of the research to society. What are the benefits of this research? Does the research create any problems (social, legal, environmental)? Which research do you consider more important?

(Write at least 1/2 page.)

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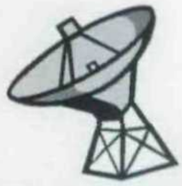

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