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Eliciting Students' Ideas and Understanding In Science: Diagnostic Assessment Strategies for Teachers

Christine Chin

If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly (Ausubel, 1968).

INTRODUCTION

Students come to science classes with prior ideas, formed through their interaction with the world around them. These ideas may arise from their personal observations and interpretations of everyday natural and physical phenomena, or be communicated to them through the media and talking with other people. While it is useful for students to have some knowledge about a science topic before learning it formally in school, some of their ideas may be misconceptions. These misconceptions (also referred to as alternative 'conceptions', 'children's science', or 'naive theories') may stand in the way of learning the 'correct' concepts. As learning involves the construction of new meanings and understandings through the linking of new ideas with existing ones, misconceptions need to be addressed as they will subsequently influence students' ability to acquire scientific conceptions.

If teachers are aware of the ideas their students bring to class, they can use these ideas as starting points and address them more effectively. This means that teachers need to take into account students' thinking and teach with their ideas in mind. The teacher should find out the ideas, beliefs, and opinions that students bring to a lesson, find out the meanings that students construct during the lesson, and assess the change and growth in these ideas. However, because of accountability pressures, teachers are more concerned with teaching the content in the syllabus and then assessing their students *summatively*, to measure the extent to which students have learnt the 'correct' or scientists' views, and to find out if they have learnt the taught material. The elicitation of students' ideas and understanding during the course of instruction is *formative* assessment in the *diagnostic* sense, and intended to assist learning. It also serves as useful feedback for teachers to tailor their teaching to the needs of the individual students and to make any adjustments where needed. As the noted educational psychologist,

Ausubel (1968) advised, it is important for teachers to ascertain students' prior ideas first and then teach accordingly.

This paper describes some strategies that teachers can use to probe students' ideas and understanding. The use of concept mapping, predict-observe-explain, interviews and students' drawings were described by White and Gunstone (1992). Bell (1993) referred to the use of journals or thinking books, surveys, the post-box technique, students' questions, brainstorming, viewfinders, and card-sorting as ways of eliciting students' ideas. Useful tips for the use of interviews and surveys are also given by Osborne and Freyberg (1985). In addition, thought experiments, students' written assignments, worksheets and tests, teacher questioning, concept cartoons (Keogh & Naylor, 1999), and class discussion may also be used. While some of these strategies may be time-consuming to use, they have been fruitful in helping researchers to identify students' misconceptions. They can be used in a normal classroom context, depending on the teacher's ability to schedule time wisely both inside and outside curriculum hours. Time spent identifying misconceptions could enable teachers to cut down on time wasted on re-teaching previously misunderstood concepts and prepare students for further learning instead.

CONCEPT MAPPING

Concept mapping is a useful technique for finding out student's conceptual structures and understanding of the interrelationship among individual concepts. First, identify the important concepts for the topic in mind (e.g. photosynthesis). Next, ask the students to write these concept labels (e.g. oxygen, carbon dioxide, sugar, starch, chlorophyll, and so forth) on pieces of paper or cards that they can manipulate physically. The students then draw concept maps by using linking words to form propositions between these concepts.

A sound understanding would be manifested as:

1. valid propositions,
2. a larger number of appropriate links and cross linkages,
3. good hierarchy (many levels, where applicable) with the most general concepts at the top and subordinate concepts at lower levels,
4. progressive differentiation, and
5. specific examples (if applicable) at the bottom of the map.

Misconceptions and poor understanding will show up as incorrect propositions, missing or faulty links between key ideas relating two or more concepts, a flat hierarchy or a linear string of words, little or

inappropriate branching, and incorrect or no examples. In figure 1a, the concept map shows good integration of many ideas with many meaningful propositions, a good hierarchical structure, valid links and examples. Contrast this with figure 1b which shows faulty propositions (e.g. bacteria is decay) and missing key concepts such as green plants (added in dotted ovals). The latter map suggests a rote, verbatim approach to learning which does not lead to acquisition of meaning. Teachers can use concept maps as diagnostic tools to identify misconceptions, assess prior ideas that students have before teaching a topic, and assess the changes and progress in students' understanding of science concepts before and after instruction. For a comprehensive account of the use of concept mapping, see Novak and Gowin (1984).

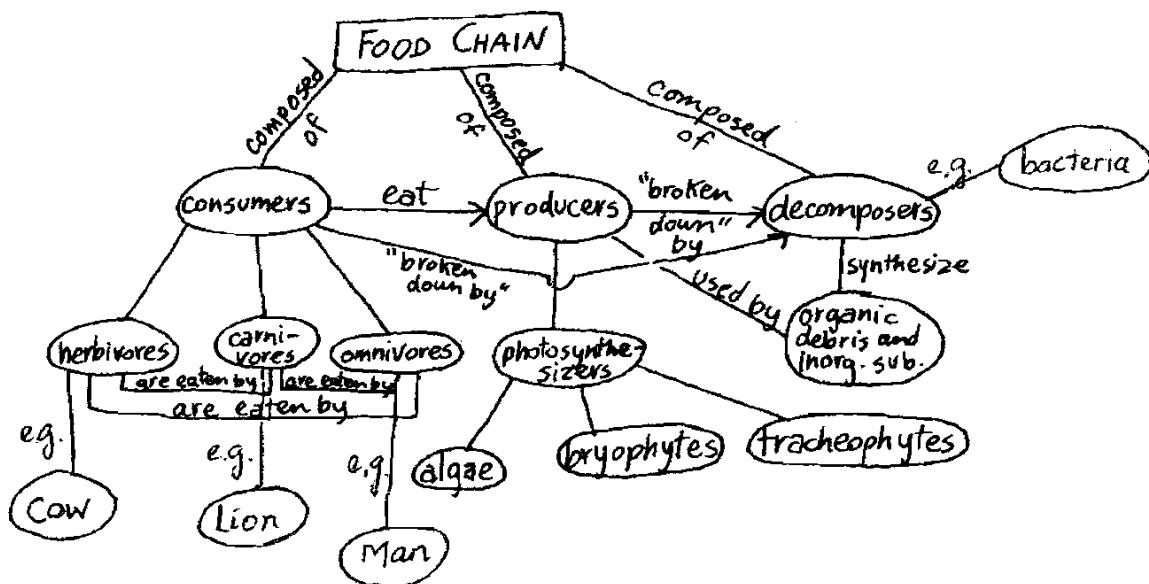


Figure 1a Concept map of the food chain showing clear understanding of concept (adapted from Novak & Gowin, 1984, p. 122).

PREDICT-OBSERVE-EXPLAIN (POE)

Give the students a situation, ask them to predict what will happen when something is done to the situation, and to justify their prediction. Next, they observe what happens. Then ask them to describe and explain what actually happened, and to explain any discrepancy between prediction and observation. Ask them to write down their responses to "What would happen if?" and "Why?". POE requires students to apply their knowledge to reason out an answer. In this process, the student's understanding of the concepts that are involved may be revealed. The activity is meant to make the familiar unfamiliar and encourage students to reconsider their beliefs. The POE strategy

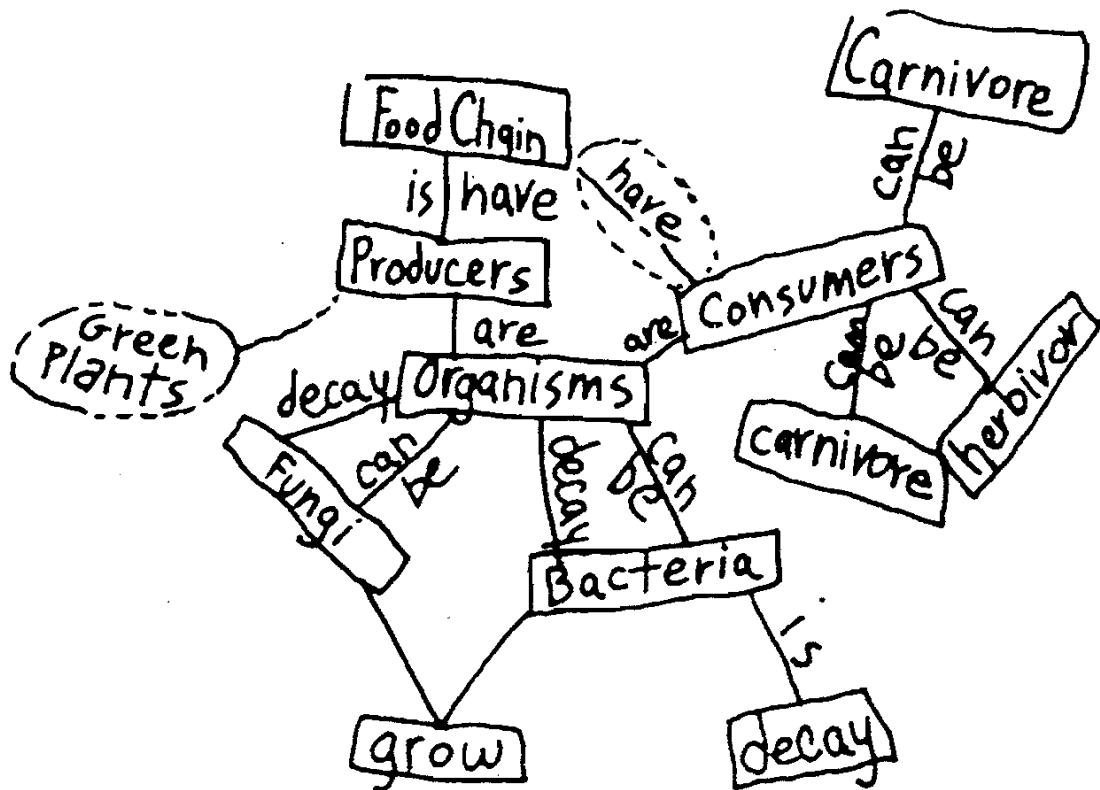


Figure 1b Concept map of the food chain showing faulty propositions or missing key concepts (Novak & Gowin, 1984, p. 124).

can be effectively used in discrepant events. The latter are situations which have surprising and paradoxical outcomes contrary to an observer's expectations. An example of a POE (White & Gunstone, 1992) was posed to students who had been taught the conservation of mass. These students were required to predict the relative weight (less, same, more) of a glass jar and its contents, after a piece of rotting liver was placed in the jar for about two weeks. The tight-fitted lid of the jar was sealed with wax to ensure that the jar was air-tight. The most common prediction and reason given was that the weight of the jar would be less as rotting caused some of the liver to disappear. Some students thought the gases had no weight. The answers revealed inadequacies in the students' understanding of the conservation of mass.

The POE technique helps to uncover deeply held beliefs about scientific principles and phenomena beyond the superficial understanding of facts and algorithms. It is best used for actual events that can be observed directly, for example, a demonstration. When using POE, it is important that the students possess some knowledge at a level they can use. If the prediction is based on pure guessing, then the experiment would be of little value. In addition, if the outcome of the event to be predicted is known unambiguously to all, then the POE technique is of limited use. Situations that students find relevant and

real in their everyday lives would be ideal. It is also important not to use POEs which always give unexpected results and to include those where students could support their predictions with observations. Otherwise, students may think that the POE is more of a trick or game, and try to predict outcomes that are unexpected rather than based on their actual beliefs and reasoning of what would happen. For more examples and details on using discrepant events in teaching and learning science, see Chin (1992).

THOUGHT EXPERIMENTS

This is a variation of the POE except that the activity to be performed is posed as an imagined scenario rather than performed physically. The outcome is then visualised. Pose the students problems such as "If an astronaut stands on the surface of the moon and releases a stone from his hand, what will happen? Why?" or "I throw a stone into water and ripples are formed. Why?". Then ask the students to discuss the question in small groups and report their answers to the class. Their responses would be indicative of their thinking, understanding, and learning.

INTERVIEWS

You can conduct one-to-one interviews with individual students about their understanding of the meaning of a word (e.g. work, force, animal) or phenomenon (e.g. evaporation or condensation of water). To provide an initial stimulus to generate a conversation, you can use a series of cards with drawings representing situations in which science concepts are depicted. In *interview-about-instances*, show situations which include instances and non-instances of a concept. An example would be to show a cockroach and a spider, among other instances, to assess the students' concept of an insect. Ask students if the situation illustrated is an instance. Then ask them to give their reasons for their categorization. In *interviews-about-events*, use pictures or practical demonstrations of familiar, everyday situations to which the concept (e.g. evaporation) may be applied. Ask the students to give some description, explanation, or prediction about the phenomenon of interest.

The aim of the interview is to find out what students *really* believe, and not to extract a 'correct' answer. Thus, you should avoid using leading questions, rejecting 'wrong' answers or praising 'right' answers. Otherwise, the interview will yield little valuable information. Remember that in your role as interviewer, you are primarily interested in eliciting students' ideas. You can teach the students *after* the interview.

Verbal (e.g. evaluative comments) and non-verbal cues (such as raising your eyebrows in surprise on hearing what students say) can also influence the authenticity of students' responses. Your tone of voice, expression, emphasis, and intonation need to be encouraging but not suggestive of any particular answer. Effective probing of students' real ideas requires a non-judgemental approach, and the questions need to be neutral rather than leading, yet penetrating rather than superficial. The way the questions are phrased is also important. For example, phrasing a question as "Why *do you think* the water level rises?" sounds less threatening than "Why does the water level rise?". The former makes the student feel that it is what he thinks is of interest, and it does not matter if he knows the 'correct' answer. "What has happened to the water droplets?" is also a better question than "Did the water droplets go into the air?" as it is more open-ended. You can probe students' understanding more deeply by following up on their responses, asking questions such as "What do you mean by that?" and "Why do you say that?". Use a mixture of closed and open questions — this will give students some confidence, yet help to avoid monosyllabic or short answers and encourage elaboration of responses.

Examples of the use of interviews in uncovering students' misconceptions about plants, animals, light, force and motion, and electric current are found in Osborne and Freyberg (1985). Interviews have also helped to yield information about what students think pertaining to matter, the Earth, and heat and temperature (Driver, Guesne, & Tiberghien, 1985).

STUDENTS' DRAWINGS

Students' drawings can reveal their understanding. Because drawings are open-ended, unsuspected understandings can be uncovered. The non-verbal nature and graphic format of drawings can also expose vagueness in conceptions that may be disguised in verbal responses. An interesting example is given by White and Gunstone (1992). After learning about photosynthesis, that green plants make their own food in the presence of light while mushrooms do not, students were given a drawing of a green plant and a mushroom in a box, with light coming in from the side. They were to draw how the plant would look like in a week's time. The expected response was that the green plant would bend towards the light. The unexpected response of one student was a drawing showing the absence of the green plant, and the presence of a leaf protruding from under the mushroom cap. The student thought that the mushroom could not make its own food, so it ate the green plant!

KEEPING A JOURNAL OR THINKING BOOK

Encourage students to reflect on their ideas by keeping a journal or thinking book where they can record their thoughts about various aspects of the topic. This helps to foster thinking about learning and learning-how-to-learn. You can guide the students' writing by providing specific, focused questions for them to respond to. In this way, you can tap their beliefs and understanding concerning the specific concepts that you are interested in addressing. Alternatively, you can ask students to answer more general questions such as "What questions do you have about things that you don't understand?" or "What questions do you have about things you would like to know more about?". From the students' writing, you can find out about your students' beliefs, misconceptions, feelings, and their reasons for having these ideas.

SURVEYS

Paper-and-pencil surveys can be used to find out the prevalence of commonly held views about certain concepts. The questions can be set in an open-ended format or a multiple-choice format. In the latter, include distractors that consists of common ideas that students have, such as known misconceptions, along with the scientifically-correct answer. Figure 2 shows a survey question used by Osborne and Cosgrove (1983). The scientific answer is (b) but options (a) and (d) were chosen by many students.

When a jug boils there are large bubbles in the water.
What are the bubbles made of?
(a) air
(b) steam
(c) heat
(d) oxygen or hydrogen

Figure 2 Survey question to assess students' ideas about boiling (from Osborne & Cosgrove, 1983).

For multiple-choice items, an additional question can be included for students to provide explanations for their choices and to indicate the thinking behind their answers and why those answers were selected. Haslam and Treagust (1987) and Peterson, Treagust, and Garnett (1986) respectively described their use of such two-tier diagnostic instruments for identifying students' ideas about photosynthesis and respiration in plants, and covalent bonding and structure. An example is shown in figure 3.

Which gas is taken by green plants in large amounts when there is no light energy at all?

- (1) carbon dioxide gas
- (2) oxygen gas.

The reason for my answer is because:

- (a) This gas is used in photosynthesis which occurs in green plants all the time.
- (b) This gas is used in photosynthesis which occurs in green plants when there is no light energy at all.
- (c) This gas is used in respiration which only occurs in green plants when there is no light energy to photosynthesize.
- (d) This gas is used in respiration which takes place continuously in green plants.
- (e) _____

Figure 3 A survey question on "photosynthesis and respiration in plants" used in a two-tier diagnostic instrument (from Haslam & Treagust, 1987).

True/false statements can also be used where students have to agree or disagree with the statements and explain their reasoning. In surveys using multiple-choice and true/false items which are relatively close-ended, some of the students' ideas may not be tapped because the students respond only to the given limited number of statements, and this does not always elicit other ideas they might have. However, space can be provided on the questionnaire for students to indicate any other alternative views that they might have beyond what is given in the item statement. The responses from the completed surveys can be collated, analyzed, and the trends and patterns noted. Such a survey questionnaire can be used as a diagnostic tool to give the teacher some indication of her students' beliefs prior to teaching the topic and upon which subsequent teaching can be based. The questionnaire can also be administered again later after teaching the topic. This would provide feedback to the teacher about the evolution and progress of students' ideas, and the effectiveness of the teaching in eradicating misconceptions.

POST-BOX TECHNIQUE

This technique relies on anonymity to find out the ideas of individuals in a large group. First, write a set of questions to elicit students' ideas.

Students then individually write their responses to each question on separate pieces of paper, with the question number at the top (names are not indicated). The answers to each question are collected in separate boxes. Groups of about five students are then given the responses to one question to summarise and record on paper or an overhead transparency. Each group presents to the class their summary of what everyone wrote in response to the given question. The class discussion arising from this can provide insight about students' thinking and misconceptions.

STUDENTS' QUESTIONS

Students' questions can reveal their thoughts, misconceptions and confusion about various concepts, as well as their reasoning. Students can ask questions either orally, or write them down on pieces of paper or transparencies. To elicit questions, you can prepare a trigger activity or a suitable stimulus to get students thinking about the topic or concept of interest. This can be a table of data, a diagram, some objects, a physical set-up, and so on. For example, for the topic on the transformation of energy, you might prepare activities involving some biscuits, a plant, a picture of an animal, a radio, a glowing light bulb, a burning candle, or a stone placed on the table. Next, elicit and record the questions that students ask. These questions indicate what they are thinking about and would like to find out. Use these questions as 'thought provokers' for stimulating discussions. Teachers can then help students to find answers to their questions. You can also ask students to ask questions to clarify aspects of learning which puzzle them.

BRAINSTORMING

To find out what students are thinking, you can ask them to brainstorm and give ideas about the topic in question. This will also encourage them to make links between what they already know and the new ideas that they are going to learn about. For example, you can ask students to generate hypotheses and explanations for a phenomenon that is being studied. Record their suggestions on the board or an overhead transparency. A discussion pertaining to these elicited ideas then follows, where you can ask further questions to probe students' understanding.

VIEWFINDERS

'Viewfinders' (Bell, 1993) is a term coined to describe the phrases that a teacher can use to find out what a student is thinking. During a

dialogue between the teacher and the student(s), the teacher can use such phrases to elicit students' ideas and views about a topic. Examples of viewfinder phrases include "Why do you think/say that?", "Tell me more about that", "What do you mean by that?", "I hadn't thought about it like that before. How did you get that idea?", and "Some people think that.... How does that fit with your idea?". To successfully draw out students' ideas, it is important to convey to students that you are genuinely interested in finding out what they really think and not simply in getting a 'correct' answer. Otherwise, they may feel threatened by this interrogation or 'inquisition' and clam up or say something that they think the teacher wishes to hear instead, thus not revealing their true thoughts. The teacher's manner of speech and tone of voice would also determine whether viewfinders are successfully used.

CARD-SORTING

This activity uses small group tasks and argumentation to encourage discussion. First, draw up a list of statements pertaining to a selected topic and put them on cards. Each card contains only one statement. Some of the statements are scientifically correct, while others may be common misconceptions. Give each group of 3-5 students some of these cards. Ask them to discuss their views about the statement written on each card. Then, as a group, they are to decide whether they all agree or disagree with the statement, giving their reasons. Next, they place each card on a "agree" or "disagree" pile. A variation of this is to use pictures instead of statements. For instance, the cards can contain examples of dissolving and examples of melting. The students are then asked to sort the cards into two piles: 'dissolve' and 'melt'. Ask them to place their card on the pile only when everyone in the group agrees as to which pile it is to go on. The teacher then conducts a whole class discussion with the students based on how the cards have been sorted. During the ensuing discussion, the teacher would encourage students to talk about any disagreements or consensus within the groups, thereby drawing out some of the common misconceptions that the students might have.

WRITTEN ASSIGNMENTS, WORKSHEETS AND TESTS

Students' misconceptions can show up in the errors that they make in their written work. This is particularly when the items assess understanding and application of concepts in a new context, not the simple recall of facts. In finding out students' reasoning behind their answers, you can identify their misconceptions. When constructing such items to tap students' understanding, you can design application and

open-ended questions where students are required to express their ideas in their own words instead of reproducing standard phrases from the textbook. The idea is to get the students to generate their own answers and explanations by applying what they have learnt instead of regurgitating familiar or memorised responses that they have previously encountered. In the case of multiple-choice items where the answers are more convergent, the distractor options can give valuable feedback about the nature and distribution of students' misunderstandings. To function effectively, the distractors should be plausible answers based on common misunderstandings that students have. The alternatives to the 'correct' answer could be derived from the research literature, earlier interviews with students, or from your previous personal encounters with students' common misconceptions. To obtain further information about students' thinking behind their chosen answers, you can include an additional question such as "Why do you select this option?"

Figure 4 shows what a local Primary 5 student drew and wrote for her class assignment on the life cycle of a chicken (personal class observation). Much of the information appears to have been memorized and regurgitated from the textbook. Her diagram (a typical one found in most textbooks) appears 'correct'. However, her misconception shows up clearly in the first three sentences of her description where she reversed the order of the fertilization and incubation processes. Often, teachers do not explicitly address the idea of internal fertilization in animals such as the hen. Consequently, students may develop the idea that the rooster can somehow fertilize the egg externally when the shell has already hardened!

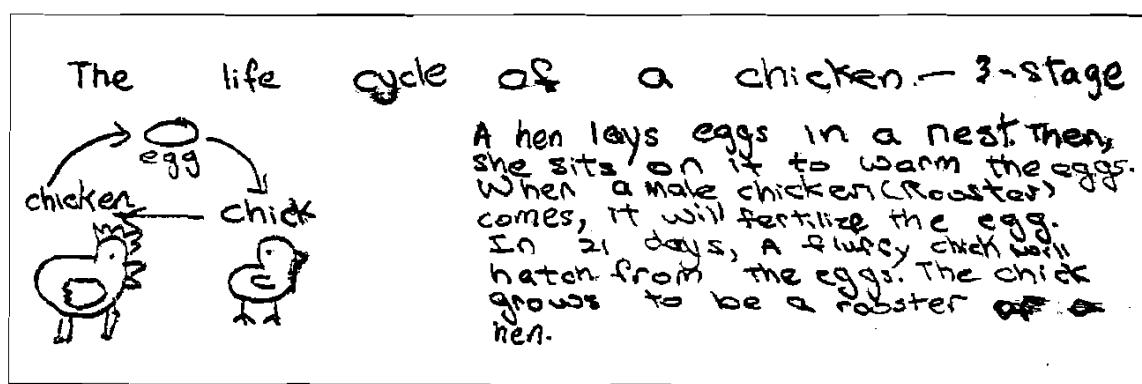


Figure 4 Student's drawing and writing from class work.

TEACHER QUESTIONING

To obtain an in-depth understanding of students' beliefs, ask probing questions that go beyond descriptions, factual recall or rote

memorization and which stimulate reasoning instead. Get the students to explain an event or phenomenon, justify their opinions, predict outcomes, hypothesize, make conclusions, or generate solutions to a problem, especially one that is in a real world context. Operational questions that ask what would happen to a system if a variable were eliminated, substituted, increased or decreased are also useful probes for eliciting students' reasoning about cause-effect relationships among variables. For example, when teaching the dissolution of sugar in water, the following questions could be asked: "What would happen if we do not stir/heat the sugar-water mixture?", "What if we use brown sugar/icing sugar/rock sugar instead of fine, white sugar?"; or "What if we use more/less sugar?". In general, ask questions that are process-oriented, seek explanations, ask for evaluations, or stimulate imagination. Place emphasis on 'how', 'why', 'what if' and on relationships to previous information. For a more detailed discussion on the effective use of teacher questioning in stimulating students' thinking, see Chin (2000).

CONCEPT CARTOONS

Concept cartoons make use of cartoon characters engaged in dialogue. They integrate text in dialogue form with a visual stimulus, represent scientific ideas in familiar, everyday contexts, and provide a stimulus for focused discussion. They present the scientifically acceptable viewpoint as well as several alternatives that are common misconceptions held by students. An example of a concept cartoon is given in Keogh and Naylor (1999, p. 436). The cartoon shows three children in a boat on the water. The first child says, "Don't go out any further. The deep water will come over the side of the boat". The second child says, "It's alright. The boat floats higher in the deep water", while the third child says, "Don't be silly! It doesn't matter how deep the water is".

Students can be asked to reflect on the concept cartoons, discuss what they think about the ideas given by the characters, and explain why they have those ideas. The cartoons can generate discussion, encourage investigation, and challenge learners' understanding. Students can also be asked to fill in blank speech bubbles to indicate what they are thinking. Cartoons are motivating, visually appealing and are especially valuable for students with weak language skills as there is minimal text. The same cartoon can be used with a variety of age groups as each group interprets the concept cartoon at their own level.

CLASS DISCUSSION

You can use the information obtained from any of the above methods

as stimuli for class discussion. A poll can also be conducted with your class about students' ideas and beliefs concerning the topic of interest. You can ask the students questions such as "How many of you think...?". Students can also articulate their ideas in small groups or large class settings, comment on their peers' ideas, and this can generate further discussion among students and between students and the teacher. The ideas elicited can promote serious debate and you can discover much about students' understanding by listening to the points that they make. During this process, students can also challenge each other's ideas and clarify misconceptions. In such an open setting, however, it is important for the teacher to provide a warm and non-threatening classroom atmosphere, with a low risk of censure, criticism, and ridicule. It takes courage for students to venture their ideas publicly and some are not comfortable with such risk-taking. If teachers are intolerant of 'wrong' or 'stupid' ideas, students will be less forthcoming in venturing their ideas, fearing that they may be dismissed as silly. However, if teachers believe that it is all right for students to make mistakes, they can plan further activities to confront the misconceptions identified and foster the development of more appropriate understandings.

CONCLUSION

This article presented several practical diagnostic assessment strategies that teachers can use during normal lessons to assess students' ideas and understanding in science. These provide a window into students' minds, and are pedagogically useful in enhancing teaching effectiveness. They can be used prior to, as well as after instruction, to enable the teacher to monitor changes in students' ideas. As over-use of any strategy can result in students' dislike for the task and trivial responses, it is good to use a variety of the strategies judiciously. Several of these strategies can also be used for summative purposes, and can reveal much about the quality of students' learning that traditional tests would miss. As White and Gunstone (1992) pointed out, the use of different assessment techniques can also help students to develop better learning strategies. When the range of procedures for assessing understanding is narrow, the understanding that is promoted is limited and lop-sided. However, when students know that these diverse probes of understanding form part of their teacher's assessment methods, this may encourage them to use more active learning strategies.

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