Primary science assessment item setters' misconceptions concerning biological science concepts

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Received 23 Dec., 2006
Revised 6 Jun., 2007

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Abstract

Assessment is an integral and vital part of teaching and learning, providing feedback on progress through the assessment period to both learners and teachers. However, if test items are flawed because of misconceptions held by the question setter, then such test items are invalid as assessment tools. Moreover, such flawed items are also likely to generate or perpetuate misconceptions among pupils. Research has shown that misconceptions among pupils are resistant to change, and that they persist even with

formal science instruction. This paper highlights question setters' (or teachers') misconceptions concerning some key primary school level biological science concepts in the areas of cells, plant and animal systems and functions. It is based on a scrutiny of more than 200 sets of primary science examination papers in schools (first and second semestral assessment science papers, i.e. SA1 and SA2) in three different contexts:

1) vetting school examination papers with a view to helping schools improve the quality of their examination questions;
2) conducting school-based workshops on how to craft better examination questions;
3) conducting in-service courses for primary school teachers.

Suggestions for addressing the problems highlighted are also discussed.

Introduction

A major theme of science education research throughout the past three decades has been students' misconceptions of scientific phenomena. The terms 'alternative conceptions' and 'alternative frameworks' have been coined to describe misconceptions or views of science that are at odds with concepts currently accepted by the community of scientists.

Studies in students' alternative conceptions (ACs) in science have a long history, being traceable back to Piaget's early work on children's views of natural phenomena (Piaget, 1929, 1930). There is now a substantial body of literature documenting the various types of alternative conceptions or preconceptions held by students in various conceptual areas (Driver & Oldham, 1985; Carmichael et al, 1991; Hershey, 2004; Pfund & Duit, 1998.) Driver et al. (1994) identified, among many other misconceptions, a number of biology misconceptions held by secondary students. One of these misconceptions was the belief held by students that respiration and breathing are labels given for the same process that occurs in mammals, including human beings. Hershey (2004) surfaced 50 plant misconceptions under five categories, namely, oversimplifications, overgeneralizations, obsolete concepts and terms, misidentifications and flawed research.

The origin of ACs have been examined by many researchers. Among the sources of ACs suggested are the following, some of which overlap:

- From everyday experience and observation (Strauss, 1981; Viennot, 1979).
- From the use of perceptual thinking, which is related to the previous source, and is seen in a number of studies where students' explanations of scientific phenomena are dominated by what is immediately perceptible (Driver, 1985; BouJaoude, 1991).
- From diagrams or statements in textbooks (Stor ey, 1992a, 1992b).
- From teachers and student teachers (Osborne & Cosgrove, 1983; Bar & Travis, 1991).

ACs or misconceptions generate more mistakes because they are incorrect representations of conceptual relationships (Strike, 1983). This means that a student's preconceptions or existing ACs hinder effective concept learning in the future. This has been shown in a number of studies (e.g., Cachapuz and Martins, 1987; Schultz et al. 1987).

Local research has shown that Singapore students and teachers are not immune to the problem of misconceptions related to basic scientific phenomena. Toh, Boo and Woon (1999) reported on Singapore students' misconceptions of light and vision whilst Boo (1995) reported on the students' misconceptions of the chemistry of burning. Boo (2006) identified a range of question setters' or teachers' misconceptions about state changes of water from a pool of primary science assessment items. However, to-date there appeared to be hardly any published papers on biology misconceptions among Singapore students or teachers.

In this paper, apparent misconceptions in the area of biological phenomena revealed in MCQ assessment items set for primary science examination papers (first and second semestral assessment science papers, ie SA1 and SA2) are discussed. It is based on a scrutiny of more than 200 sets of primary science SA1 and SA2 science papers in schools. Papers have been provided through a number of avenues: namely, vetting school examination papers with a view to helping schools improve the quality of their examination questions; conducting school-based workshops on how to craft

better examination questions and conducting in-service courses for primary school teachers. Feedback, together with suggestions on how the items could be improved, have been provided to question setters.

All items are baselined to the Singapore Primary Science Syllabus introduced by the Ministry of Education in Primary 3 (P3) in 2001 and progressively introduced into the schools with full implementation completed and tested at the PSLE (Primary School Leaving Examination) at P6 in 2004. The grade level of each question is indicated for each test item discussed: P3 to P6 (Primary 3 to Primary 6) – mainstream – corresponding to pupils aged 9-12 years.

Identified Misconceptions

2.1 Breathing and Respiration

Within the primary science syllabus, the subject matter of breathing and respiration is introduced progressively from Primary 3 (P3) to Primary 5 (P5). In P3, pupils are introduced to the concept that living things need air, water and food to survive; they are taught life cycles of plants and animals. The respiratory and circulatory systems of human beings, and plant parts and their functions are introduced in P4. Thus by the end of P4 pupils learn the different structures and organs used by plants and animals to exchange gases with the environment as well as the function of transport system in plants and circulatory system in human beings. At the P5 level, pupils learn about the processes of photosynthesis and respiration. They learn that photosynthesis is the process in which plants make food by combining water and carbon dioxide from the environment in the presence of light energy. They learn that oxygen is also produced during the process of photosynthesis. They also learn that food produced by plants becomes the source of energy for animals and other types of organisms; and that respiration is a process occurring in living cells, and by which energy is released from food and made available for life processes such as movement, growth, repair, and so forth.

In the syllabus, differentiation is made between respiration and breathing, that is,

- Breathing refers to the process that brings about an exchange of gases between the organism and its environment; and

- Respiration refers to the process that releases energy from food substances in living cells

- At the primary level the distinction between breathing as a physical process and respiration as a chemical process is not made.

However, many question setters (teachers) set questions which show confusion between these two processes.

Example Question 1 (P4)

Different living things use different parts of their body for respiration. Plants use stomata while dolphins use their _____.

(1) lungs (2) mouths

(3) breathing tubes (4) gills

Example Question 1 illustrates the confusion in the question setter's mind. The intended answer is Option 1 – lungs. The question stem refers to respiration whereas the options provided and the intended answer are specifically parts concerned with breathing or the process of that brings about gaseous exchange between organisms and their environment.

One possible cause of this particular misconception could be the universal use of the term "respiration" to refer to aspects concerning the breathing system – particularly in human biology and medicine where the nostrils, windpipe, lungs together with the mechanical actions of the diaphragm and rib cage are referred to as the respiratory system and lung diseases such as bronchitis and pneumonia are termed respiratory ailments.

Example Question 2 (P4)

Breathing is the process of

_____.

(1) converting glucose into oxygen

(2) converting oxygen into glucose

(3) taking in air into our bodies and giving out oxygen

(4) taking in air into our bodies and giving out carbon dioxide.

An incomplete understanding of breathing is shown in Example Question 2 which is also taken from the P4 level. In this example the intended answer is option 4. However, what is breathed out is not just carbon dioxide. The correct concept is that the air that is

breathed in is relatively rich in oxygen (about 21%) and poor in carbon dioxide (about 0.03) whilst the air that is breathed out is poorer in oxygen (about 16%) but richer in carbon dioxide (about 4%).

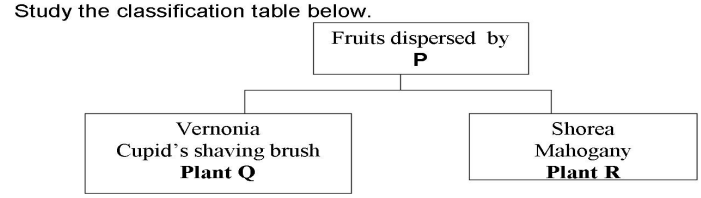
2.2 Plant Reproduction

Life cycles of plants and animals are introduced at the P3 level and pupils should be engaged in practical activities to grow plants from seeds in order to observe the complete plant life cycle. The topic is revisited at P5 when pupils study the various reproductive processes employed by plants including sexual reproduction of flowering plants

In testing pupils on the diverse methods of seed dispersal used by different plants, often question setters will refer to 'fruit dispersal' rather than the correct concept of 'seed dispersal'. This appears to suggest that fruits have been misconceived as having the potential to develop into new plants, when in actual fact, fruits either get eaten or decomposed. It is the seed that has the potential for growing into new plants. This conceptual error is illustrated in example question 3, where the intended answer is option 1. The root cause of this error is likely to be the influence of simple perceptual reasoning: an animal eats the fruit or the fruit splits and ejects the seeds.

Example Question 3

Study the classification table below.



Which of the following can be P, Q and R?

	P	Q	R
(1)	Wind	Lallang	Angsana
(2)	Water	Nipah	Mangrove
(3)	Wind	Angsana	Lallang
(4)	Water	Mangrove	Nipah

Another related problem concerns a prevailing misconception that, in the life cycle of a flowering plant, the fruit develops before the seeds. The correct concept is that upon union of the female gamete (in the ovule) with the male gamete (from the pollen), the seed is formed, and only after that, the fruit develops from the ovary. In other words, the fruit is developed only after the process of fertilization which results in the seed formation, as a by-product of the reproductive process. The fruit develops to protect the seeds, and in some cases, develop to become "attractive" to animals that will be

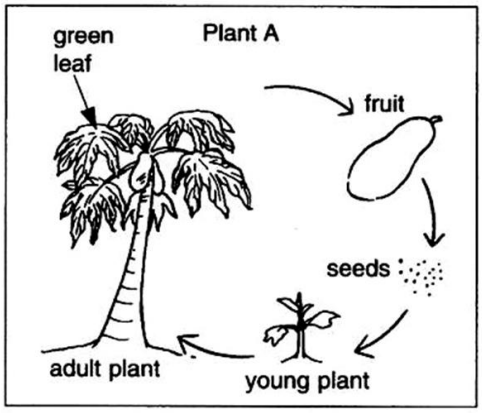
the agents of seed dispersal. This misconception is shown in Example Question 4 taken from a P6 paper.

The same misconception is shown in Example Question 5, also from a P6 paper. In this question the intended answer is option 4 when in actual fact, none of the options is correct.

The option that is closest to the correct answer would be option 3, which should be modified by removing "fruits" completely and drawing an arrow from "seeds" to "seedlings" as shown in figure 1 below to make it acceptable as the answer key.

Example Question 4 (P6)

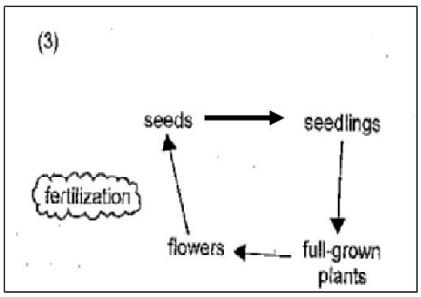
The diagram below shows how Plant A reproduces.



Which one of the following statements is most likely to be true?

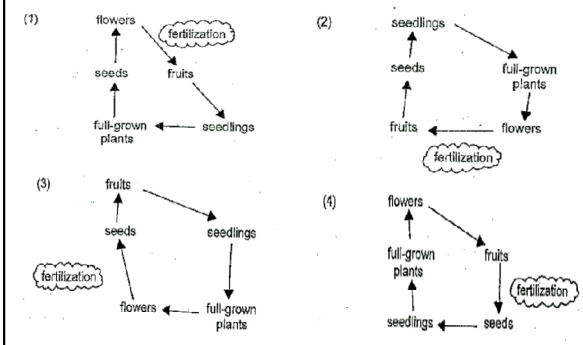
(1) Plant A grows in shade.
(2) Plant A is a flowering plant.
(3) Plant A is a non-green plant.
(4) Plant A takes one year to complete one life cycle.

Figure 1 Modified option 3



Example Question 5 (P6)

Which one of the following shows correctly the life cycle of a plant with fertilization taking place at the correct stage?



2.3 Cell Structures and Mechanisms

Cell Structures and mechanisms are covered at the P5 level. The learning objectives are identification and understanding of function of the parts of plant and animal cells and the understanding of organism growth through cell division. Even within this

quite limited subject scope questions involving cell structures and mechanisms show a number of misconceptions amongst question setters. Example Question 6 which asks for the common parts found in all cells, the intended answer is option 4 indicating that all cells have cytoplasm, cell membrane, nucleus and cell sap. However, not all cells have nuclei, examples being bacterium cells and red blood cells of human beings. Also, not all cells have cell walls; examples being animal cells. This misconception illustrates one of the problems with biological systems as compared to physical systems and that is the greater scope for variability and exceptions within broad categories and therefore the problem of using terms like 'all' and 'every' in biology MCQ test items. Whilst the generalizations are useful at a macroscopic level, the scope for variation from the general case is great and many pupils will be aware of the typical exceptions.

Example Question 6 (P5)

All living things are made up of cells. What are the common parts found in all cells?

A: Cell wall
B: Cytoplasm
C: Cell membrane
D: Nucleus
E: Cell Sap

(1) A and E only
(2) B and D only
(3) B, C and D only
(4) B, C, D and E only

In example question 7, the intended answer (option 1) suggests an over-simplification of cells structures. Here the question setter appears to think that the cell size in whales is more or less the same as that in the housefly. There appears to be a lack of understanding of the diverse cell structures and functions in multi-cellular organisms, and that it is meaningless to make a gross comparison of cell sizes in two such dissimilar multi-cellular organisms.

Example Question 7 (P5)

Which one of the following sentences is false?

1. The cells of a whale are much larger than that of an ant.
2. The cells in our body continue to grow and divide to replace the old and damaged ones.
3. The nucleus controls most of the cellular activities within the cell.
4. The cell wall gives plant cells a regular shape.

2.4 Human Systems

In addition to the misconception regarding breathing and respiration mentioned earlier several other aspects of human systems give rise to difficulties amongst question setters. Different aspects of human systems are introduced at stages throughout the primary science curriculum. Digestive and muscular/skeletal systems are covered in P3, respiratory and circulatory systems in P4, reproduction in P5 along with greater depth of understanding of respiration.

Example Question 8 (P3)

Which of the following systems interact together to enable us to move?

A. muscular system

B. digestive system

C. respiratory system

D. skeletal system

(1) A and B only (2) A and D only

(3) B and C only (4) A, C and D only

The most common problem is that question setters appear to take a one dimensional view of the different systems and often fail to appreciate the necessary levels of inter-working between systems that take place in order for the body to function.

Example Question 9 (P5)

Which of the following statements about your body system at work is false?

(1) Your digestive system is at work when you hear your stomach growling before recess.

(2) Your muscular system is at work when you pant after running around the field during PE.

(3) Your skeletal system is at work when you bend your fingers to grip a pencil when writing.

(4) Your circulatory system is at work when you hear your heart thumping before you sit for an examination.

This one dimensional view is illustrated in Example Question 8 taken from a P3 paper. The teacher's intended answer is option 2 – indicating that only the muscular and skeletal systems interact to enable movement. Most pupils will recognize that all of these systems interact in some way to enable movement. The skeletal system provides the anchorage for the muscles from which they can exert contraction; the digestive system is just as important as the respiratory system in providing muscle cells with the raw materials for the energy release that powers the muscles.

A similar one-dimensional view appears to be the problem in Example Question 9, from a P5 paper. The question setter's intended answer is option 2 – indicating that no

muscles are working at the end of the run. However, at the end of the exercise run, the chest will be heaving, the diaphragm moving and the heart pumping – these are parts of the muscular system. Therefore, none of the statements is false and so no correct answer key is available. The problem identified in questions 8 and 9 is not really one of misconceptions, but rather one of poor item crafting as discussed in the following section under "Discussion". Perhaps question 8 could be crafted in a tighter, more specific way such as: "Which of the following systems act as levers to enable us to move?"

Discussion

The example assessment items discussed in this paper demonstrate some of the misconceptions held by question setters concerning basic biological science concepts.

Whilst some of the misconceptions may be due to poor item crafting - particularly ambiguity posed by the framing of the items and the failure to anticipate the different possible perspectives that the students might have, it has been found through interactions with teachers in various informal settings that these misconceptions are indeed held by some teachers.

This would support the suggestion by many researchers that teachers can be the source of many of the misconceptions held by students.

Many in-service teachers in the primary schools either do not have a science background or are only practicing science teaching for a small part of their teaching time (being generalist teachers who are also involved in the teaching of English Language and Mathematics). It would therefore be beneficial for primary teachers to attend in-service programs and practical science workshops where they could explore these basic concepts in greater detail.

Poorly crafted assessment items not only invalidate the assessment process but disadvantage students, particularly the more creative ones, who are often able to see the correct concept or see alternate views of the problem not considered by the question setter but who have no means in an MCQ item to convey their understanding. One way of addressing this issue is to add a second tier to the MCQ, where the added second tier is an open-ended segment which allows students to explain their reasons

for choosing a particular option as their answers given in the first part of the MCQ (Boo, 2003; Boo & Ang, 2005).

It is recommended that all test items be subject to rigorous quality review to ensure correct expression of science concepts in the questions and in the intended answers. Quality review is particularly important in the case of MCQ items which provide no means for the student to express alternate ideas to those held by the teacher and articulated in the question. In many schools, external review has been demonstrated to be highly cost effective in surfacing teacher misconceptions and improving the quality of assessment items.

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