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 life science concepts in the areas of cells, plant and animal systems and functions. It is based on a scrutiny of numerous 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 National Institute of Education in-service courses for primary school teachers.

Suggestions for addressing the problems highlighted are also discussed.

1. 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; Pfund & Duit, 1998; Carmichael et al, 1991).

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 (Blosser, 1987; Cho, Kahle & Nordland, 1985).
* 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' perceptions of light and vision whilst Boo (1995) reported on the understanding of the chemistry of burning. Boo (2006) identified a range of 'teachers' misconceptions about state changes of water from a pool of primary science assessment items.

The traditional multiple choice question (MCQ) comprising a stem and a set of options from which the student has to choose one and only one option as the correct answer form the large majority of test items in both teacher-crafted tests used in schools as well as in public examinations such as the PSLE (Primary School Leaving Examination) science paper. These MCQs require the question setter (usually, the teacher) to craft a question that is completely accurate in the concepts presented otherwise the student who has the correct understanding can be confused as to the question setter's real question. If the concept is not fully understood by the question setter then either inappropriate options can be presented to the student or a question can be set that has either no correct answer or more than one acceptable answer. In any of these cases, the student who understands the correct concept is severely disadvantaged since, in the MCQ, there is no mechanism for the student to offer an alternate understanding to the erroneous one presented by the setter.

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. Papers have been provided through a number of avenues: 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 NIE (National Institute of Education) in-service courses for primary school teachers. Feedback, together with suggestions on how the items could be improved, has been provided to question setters.

All items are baselined to the Singapore Primary Science Syllabus introduced by the Ministry of Education in 2001 and progressively introduced into the schools with full implementation completed in 2004. The grade level of each question is indicated for each test item discussed: P4 to P6 (Primary 4 to Primary 6) – mainstream – corresponding to students aged 10-12 years.

2. 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 the various parts of plants and their basic functions but this is not elaborated into an understanding of breathing or respiration. The respiratory and circulatory systems of plants and animals are introduced in P4 and students learn the different structures or organs used by plants and animals to exchange gases with the environment. At the P5 level, pupils learn that water, carbon dioxide and light energy are needed for photosynthesis, a process in which food (in the form of sugar or glucose) and oxygen are produced; that the 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 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 movements that cause exchange of gases between the organism and its surroundings;
- Respiration refers to the activity that releases energy from food substances in living cells.
However, many question setters (teachers) set questions which show confusion between these two processes.

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 the process of breathing.

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 lungs and windpipe, 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.

An incomplete understanding of breathing is shown in Example Question 2 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%).

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 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.
2.2. Life Cycles of Living Things

The subject area of life cycles generates a number of misconceptions and errors in the use of terminology.

Life cycles in different organisms 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.

Often question setters will refer to ‘fruit dispersal’ rather than using the correct concept of ‘seed dispersal’. Fruits do not develop into new plants. They 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. 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.

Another related problem concerns a prevailing misconception that in the life cycle of a flowering plant, the misconception that 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 after that, the fruit develops. That is, it is only after the process of fertilization which results in the seed formation that the fruit develops, 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 which is incorrect since this option shows the seeds developing after the fruit. In this example, no correct answer key is provided. An acceptable option for this question could be created by modifying the given option 3 by the inclusion of an arrow from the seed to the seedling and omitting the arrow between the fruit and the seedling; the fruits would then be correctly represented as an offshoot from the cycle (see Figure 1).
Many teachers appear to have the misconception that each plant type is limited to one method of reproduction whereas some plants are able to reproduce themselves by several different methods. This misconception is illustrated in Example Question 6 where the intended answer is option 2 showing that the question setter only allows for one type of reproduction in each group. The reality is that sansevierias and begonias can grow from stems (suckers, tubers, rhizomes) and as well as from leaves; bananas and pineapples can grow from seeds as well as from suckers; sweet potatoes and radishes can grow from seeds as well as from roots.

2.3. Cell Structures and Functions

Cell structures and functions 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. Two different misconceptions within this topic are shown in the example questions 7 and 8.

In Example Question 7, 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 red blood cells and bacterium 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 exception 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 macro level, the scope for variation from the general case is great and many pupils will be aware of the typical exceptions.

In example question 8, the intended answer (option 1) suggests an oversimplification of cell 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.

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.

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.

This one dimensional view is illustrated in Example Question 9 taken from a P5 paper. The teacher’s intended answer is option 2 – indicating that only the muscular and respiratory 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 10, also 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.
3. Discussion

The example assessment items discussed in this paper demonstrate some of the misconceptions held by question setters concerning basic life 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 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 practising 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 programmes 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.

4. References


