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# **Teachers' Misconceptions of Biological Science Concepts as Revealed in Science Examination Papers**

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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 perpetuate the 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 teachers' (or question setters') misconceptions concerning some key biology science concepts in the areas of plant and animal morphology, function and genetics. It is based on a scrutiny of numerous sets of primary science examination papers in Singapore Schools (first and second semestral assessment science papers, ie 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.

## **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, 1991; 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' misconceptions of light and vision whilst Boo (1995) reported on students' conceptions about the chemistry of burning. Boo and Ang (2004) identified a range of teachers' misconceptions about some life science and physical science concepts 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 science paper. These MCQs require the question setter (usually, the teacher) to craft a question that is accurate in the concepts presented otherwise the student who has the correct understanding could 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 scientifically correct answer key or has 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) will be 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.

## Identified Misconceptions

### Breathing and Respiration

Within the Singapore 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 basic need of all living things for water, food and air to survive; pupils 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 pupils learn the different mechanisms used by plants, animals and fishes to exchange gases with the environment. At the P5 level, pupils learn that water, light energy and carbon dioxide are needed for photosynthesis and the production of sugar and oxygen; that the food produced by plants becomes the source of energy for animals and that respiration is a mechanism by which energy is made available for all life process to occur.

Despite the curriculum objective to teach the correct differentiation between respiration and breathing,

- Breathing refers to the mechanism that causes exchange of gases between the organism and its environment;
- Respiration refers to the process that releases energy from food substances in all living cells

many teachers set questions which confuse the two.

#### 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 clearly 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 matters 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% oxygen) and poor in carbon dioxide (about 0.03%) whilst the air that is breathed out is poor in oxygen (about 16%) but rich in carbon dioxide (about 4%). The nitrogen content of the air is unchanged in the breathing process.

A further example of the potential for confusing breathing and respiration is shown in Example Question 3 taken from the P6 level. In this example, the question setter wrongly draws the analogy of breathing with burning rather than of respiration with burning. Breathing is essentially a physical, mechanical process whereas burning, like respiration is a chemical process – both respiration and burning being exothermic redox reactions. The analogy of respiration with burning is therefore, in general, a good one. One further problem with the Example 3 question is that option A – carbon dioxide is given off – whilst true for the respiration reaction is only partially true for burning reactions, only the burning of carbon containing substances will result in the formation of carbon dioxide.

## Plant Reproduction.

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

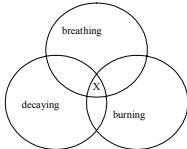
### Example Question 2 (P4)

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.

### Example Question 3 (P6)

The Venn diagram represents three processes. Which of these conclusions can be represented in the intersection of the three circles drawn, that is, area X in the diagram?

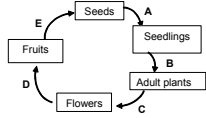


- A. carbon dioxide is given off
- B. oxygen is taken in
- C. sunlight is needed
- D. new substances are formed

1. A and B only
2. B and C only
3. B, C and D only
4. A, B and D only

### Example Question 4 (P6)

The diagram below shows the stages of growth of a plant.



The processes of fertilization and germination take place at \_\_\_\_ and \_\_\_\_ respectively.

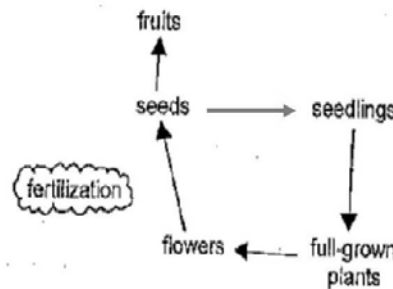
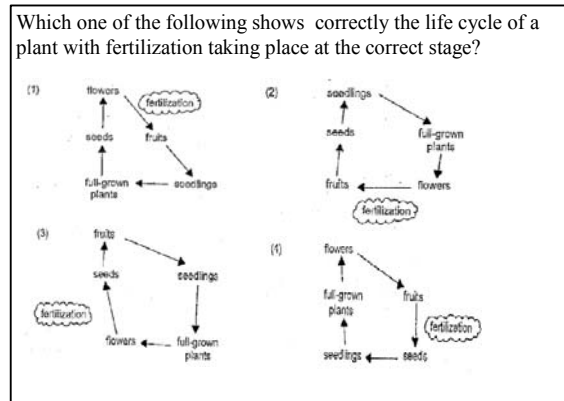
	Fertilization	Germination
1)	A	C
2)	C	E
3)	D	A
4)	E	B

plants including sexual reproduction of flowering plants.

A common misconception is that the flower first produces a fruit and that seeds are formed after the fruit whereas the correct concept is that upon fertilization, i.e., the union of the female gamete in the ovule with the male gamete in the pollen after pollination, the seed is formed. The fruit develops only after the seed is formed. The fruit develops to protect the seeds, and in some cases to become attractive to animals that will be the agents of seed dispersal. This misconception is shown clearly 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 whereas no correct answer key is provided. The correct drawing in answer to this question would be:

**Example Question 5 (P6)**



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 sansevieria can grow from suckers and/or leaves; begonias can reproduce from tubers, rhizomes or leaves and radishes can be grown from seeds.

have the misconception

**Example Question 6 (P5)**

The table below shows some plants that have been grouped according to the way they reproduced.

Group A	Group B	Group C	Group D
Begonia	Banana	Potato	Sweet Potato
Sansevieria	Pineapple	Water Chestnut	Radish

Which of the following shows the correct method of reproduction for the group A, B, C, and D?

	Group A	Group B	Group C	Group D
(1)	Leaves	suckers	Underground roots	Underground stem
(2)	Leaves	Suckers	Underground stems	Underground roots
(3)	Suckers	Underground roots	Underground stems	Leaves
(4)	Suckers	Leaves	Underground roots	Underground stems

## 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.

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, an example being red blood 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.

A common misconception amongst teachers is that cells continue to grow as the organism matures and that it is cell size that is the determinant of organism size. At a simple level, this misconception is illustrated in Example Question 8. The question setter's intended answer is option 1 – that the cells of a whale are bigger than those of a housefly is a false statement. The intended answer is problematic since there are a variety of different cell types in whales and houseflies. It is likely that many cells in whales are bigger than many cells in flies.

A more detailed example of the same misconception is shown in Example Question 9. Here the question setter's intended answer is option 3 indicating the misconception that cell growth is a contributor to increased body mass of an animal. Cells only grow to the point at which they divide and so do not contribute to macro level organism growth. The correct answer should be option 2 – increase in body mass of an animal is due to cell division only. However, it should be noted that C – cell death – is also happening but the

### Example Question 7 (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

### Example Question 8 (P5)

Which one of the following sentences is false?

1. The cells of a whale are much larger than that of a housefly.
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.

### Example Question 9 (P5)

An animal M had a mass of 3g when it was 1 week old. It had a mass of 28g when it was 4 weeks old. Which of the following would have contributed to the increase in mass?

- A: Cell growth
- B: Cell division
- C: Cell death

- (1) A only
- (2) B only
- (3) A and B only
- (4) B and C only

number of new cells created by cell division exceeds the number of cells dying.

## Human Systems

In addition to the misconception regarding breathing and respiration mentioned earlier several other aspects of human system mechanism give rise to difficulties amongst teachers. Different aspects of human systems are introduced at stages throughout the Singapore 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 teachers 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 takes place in order for the body to function.

This one dimensional view is illustrated in Example Question 10 taken from a P5 paper. The teacher's intended answer is option 2. However, at the end of the exercise run, the chest will be heaving, the diaphragm moving and the heart beating – all of these are muscular systems. Therefore, none of the statements is false and so no correct answer key is available.

Similarly in Example Question 11, also from a P5 test paper, the intended answer of option 1 – circulatory and digestive systems – is likely to cause problems for many pupils who will rightly see that if the respiratory system is not working then neither will be the circulatory or digestive systems.

### Example Question 10 (P5)

Which of the following statement 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 P.E.
- (3) Your skeletal system is at work when you bend your fingers to grip the pencil when writing.
- (4) Your circulatory system is at work when you hear your heart thumping before you sit for an examination.

### Example Question 11 (P5)

Which of the 2 systems in the table below must work together so that digested food can be transported to the cells in our body?

	Type of Systems
A	Circulatory
B	Digestive
C	Respiratory
D	Skeletal

- (1) A and B
- (2) A and C
- (3) A and D
- (4) B and C

## Discussion

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

Whilst some of the misconceptions may be due to poor item crafting - particularly the failure to see all the possible perspectives that the students might see, it has been found through interactions with teachers that these 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 time. It is probably therefore beneficial for primary teachers to attend occasional practical science workshops where they could work explore the key biology concepts in greater detail. For example, in the area of plant morphology, they could be presented and experiment with a wide range of plant types to show how the same species can reproduce by multiple methods..

Poorly crafted assessment items not only invalidate the assessment process but disadvantage students, particularly the more creatively able, who are often able to see the correct concept or see alternate views of the problem not considered by the teacher but who have no means in an MCQ item to convey their understanding.

It is recommended that all test items be subject to rigorous quality review to ensure correct expression of science concepts both in the question stem and in the offered alternates of MCQ items. 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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