Title	Teachers' misconceptions of science as revealed in science examination papers
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Teachers' Misconceptions Of Science 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 an assessment tool. This paper highlights some common misconceptions found in a sample of 100 primary science examination papers. These include question setters' misconceptions concerning energy and force, effects of heating and cooling, changes in states of matter, respiration and breathing. Specific questions where misconceptions are found are discussed.

Introduction
Assessment is an integral and vital part of teaching and learning. It provides feedback to learners on the effectiveness of their learning and feedback to teachers on the effectiveness of their teaching. However, where test items are flawed in themselves because of misconceptions held by the question setter, then not only would test items become invalid means of measuring effectiveness of learning and teaching, but would also be unfair to learners who have spent much time studying and revising for the test or examinations.

Over the past four years, the first author has been scrutinising school science examination papers 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 NIE (National Institute of Education) in-service courses for primary school teachers.

Based on 100 copies of primary science papers examined (from Primary 4 to Primary 6 (excluding P5 EM3 and P6 EM3 papers), sample questions which illustrate some of the misconceptions held by setters are highlighted and discussed in the following section. These misconceptions, surfaced from examination papers, have also been shown to exist among some teachers by the use of a simple questionnaire, sample items on which are at Annex 1.

Sample Questions and Assessment Comments

Question 1 (Level: 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.

Intended Answer:

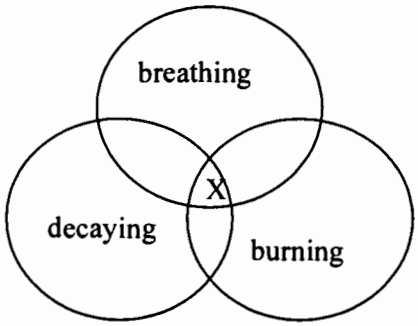
Option 4

Comments

The surface presentation of options and the question setter's intended answer suggest a misconception that breathing involves the complete conversion of air to carbon dioxide. The correct conception is that we breathe in normal, atmospheric air, which is a mixture of about 78% nitrogen, 21% oxygen, 1% noble gases, 0.03% carbon dioxide and varying amounts of water vapour and other gases which differ from place to place, and breathe out air which has the following composition (78% nitrogen, 16% oxygen, 4% carbon dioxide and saturated with water vapour). This means that exhaled air is poorer in oxygen (16% oxygen compared to 21% in inhaled air) and richer in carbon dioxide (4% compared to 0.03% in inhaled air).

Question 2 (Level: P6)

The Venn diagram represents three processes.



Which of these conclusions can be represented by the area marked '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

Intended Answer:

Option 4

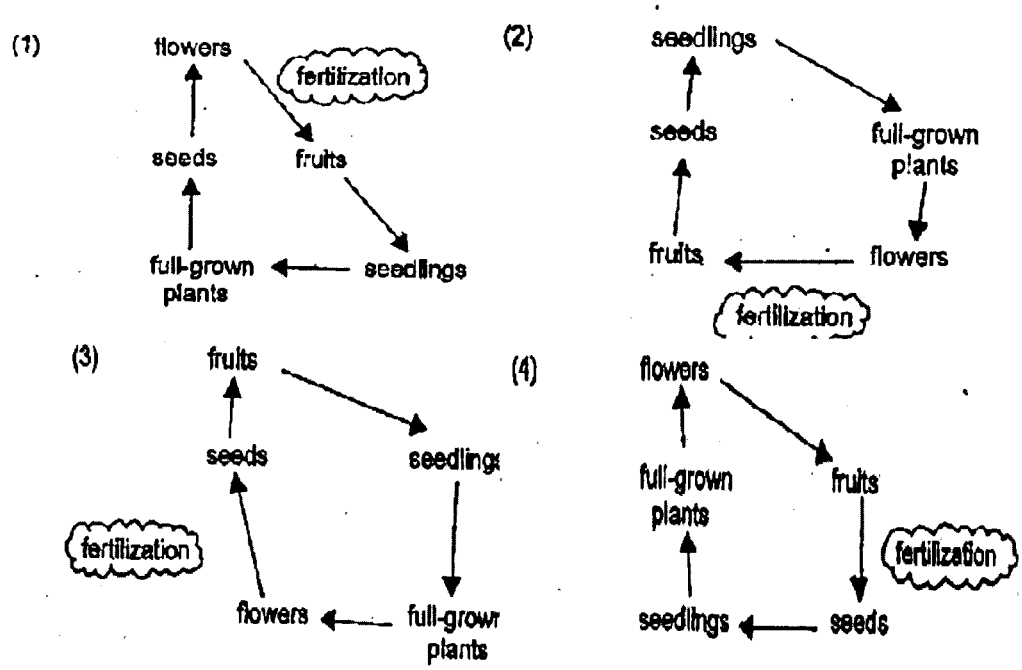
Comments

The intended answer 4 is problematic because breathing has been misconceived as a chemical change producing new substances; here it has been misconceived as meaning the same as respiration. Breathing should be differentiated from respiration in that breathing is the process that brings about an exchange of gases between an organism and the environment, and it is a mechanical process which does not involve the production of new substances. More specifically, in human beings, it refers to the muscular contractions and movements of the ribs which result in the movement of air in and out of the lungs. In contrast respiration refers to the process which takes place in every cell of an organism whereby food substances are oxidised (for example, glucose being reacted with oxygen taken in during breathing and being converted into carbon dioxide and water vapour) and energy is released for life processes. Another problem with the intended answer 4 is that it assumes that burning results in carbon dioxide being given off. This assumption holds true only if fossil fuels are burned. For example when hydrogen is used as a fuel, no carbon dioxide will be produced, and the only product is water vapour.

Another problem with this question is the phrasing of the question stem. An example of a more appropriate stem would be "The Venn Diagram represents 3 sets of characteristics associated with breathing, decaying and burning respectively. Which of the following characteristics could be represented by the area marked X?"

Question 3 (Level: P6)

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



Intended Answer:

Option 4

Comment

The intended answer 4 is not the best answer. It reveals a misconception that in the cycle of development of a flowering plant, the fruit develops before the seed. The more correct conception is that the seed develops first (via the union of the female cell in the ovule with the male cell in the pollen), after which a series of hormonal changes occur which causes the ovary to develop into a fruit to protect the seed. This means that option 3 is a more correct answer than the intended answer (option 4); however, a further improvement should be made to option 3 by shifting the arrow which links "fruits" and "seedlings" in such a way that it now links "seeds" and "seedlings" (since it is the seed that develops into a seedling and not the fruit); this would correctly leave the fruit as an ancilliary item in the cycle.

Question 4 (Level: P4)

Which of the following can reflect sunlight?

A a mirror

B a cardboard box

C a silver coin

D a white shirt

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

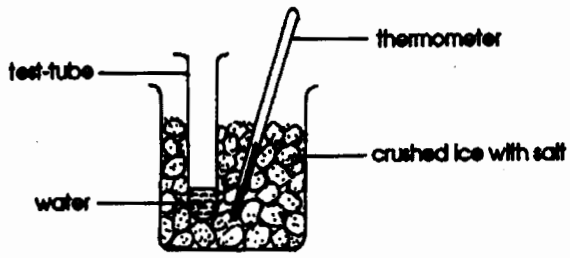
Intended Answer

Option 2

Comments

The intended answer 2 shows that the question setter thinks that only the three shiny objects (mirror, silver coin and white shirt) reflect sunlight but not the relatively matt cardboard box. The correct conception is that all but black coloured objects reflect light (artificial as well as sunlight) into our eyes which make them visible. Black coloured objects absorb light and we see them through the contrast with other objects which reflect light into our eyes.

Question 5 (Level: P5)



What is most likely to happen in the above experiment?

(1) The water turns into ice.

(2) The water evaporates.

(3) There is no change in the volume of water.

(4) The amount of water in the test tube increases. ( )

Comments

As presented, this is a very problematic question. The intended answer 1 is not the best answer because whether the water in the test tube will turn into ice or not depends on the

amount of water in the test tube and the temperature of the mixture of crushed ice and salt in the beaker and the starting temperature of the water. If the amount of salt added to the crushed ice is not significant, then the temperature of the mixture of crushed ice and salt may not be low enough to cause the water in the test tube to lose so much heat that its temperature drops to 0°C, and then freezes, which requires more heat to be lost to the surrounding ice-salt mixture. The effect of adding salt (or any other impurity) to ice is to lower the melting point of ice. The temperature of a mixture of ice and salt could be as low as nearly 21°C at normal atmospheric pressure. It should also be noted that two other effects are likely with this set-up. Firstly, if the surrounding atmosphere is warm and moist (typical in Singapore) then some condensation is likely to occur on the inside of the test tube which will add to the volume of water in the tube, hence option 4 could be correct. Secondly, evaporation takes place from the water surface at all temperatures, so option 2 is also correct; in fact among the three acceptable answers (options 1, 2 and 4), option 2 is the most likely and hence the best answer. Clearly there are several factors that would need to be taken into account in answering this question. At the P5 level, the pupils will have been exposed to the underlying concepts of condensation, evaporation, melting and freezing.

Question 6 (Level: P5)

When water in a kettle is boiling, which of the following do you think is/are taking place?

A. The temperature of the water is increasing.
B. Water is changing into water vapour.
C. Large bubbles of air are forming in the water.

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

Intended Answer:

Option 3

Comments

The intended answer 3 is incorrect. The bubbles seen in boiling water are bubbles of steam (gaseous water or water vapour at 100°C). Therefore, no correct answer key is offered since the only correct answer is statement B "Water is changing into water vapour". Some teachers fail to understand the process difference between evaporation and boiling. Evaporation is the escape of higher energy molecules of the substance from the surface of the liquid and takes place at all temperatures throughout the liquid phase. Boiling takes place at a fixed temperature for a pure liquid (known as the boiling point of the liquid) at normal atmosphere and occurs throughout and from within the body of the liquid and involves the conversion of liquid into gaseous phase.

Question 7 (Level P5)

Meiling was trying to dissolve some sugar in water. Which of the following will affect the rate at which the sugar dissolves?

A. the speed of stirring

B. the amount of water used

C. the amount of sugar used

D. the temperature of the water used.

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

Intended Answer:

Option 4

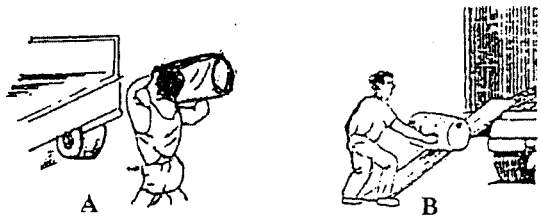
Comment

The intended answer 4 is problematic and suggests a confusion in the question setter's mind between the amount of solute that can be dissolved in a given quantity of solvent and the speed at which dissolving happens. Dissolving is a process that involves interaction between solute and solvent particles and takes place at the point of contact between the solute and the solvent to form the solution. The rate at which this interaction takes place is dependent on the surface area of contact between solute and solvent particles as well as the speed at which particles of solute and solvent are moving. Assuming the normal context of dissolving in which a small amount of solute is being dissolved in a large amount of solvent, additional amount of solvent will not affect the surface area of contact between the solute and the solvent, hence amount of solvent does not affect the rate of dissolving (hence option B is not the answer). Increasing the amount of solute will increase the surface area of contact between solute and solvent; however, rate of dissolving is unaffected because rate is defined as amount of solute dissolved per unit time, hence option C is not the answer. As an analogy, the speed of travel from point X to point Y is dependent on the engine power (say of the legs if one is walking or of the vehicle if one is used) and is independent of the distance to be covered. Once particles of solute are completely surrounded by particles in the newly formed solution, and so are no longer in contact with particles of solvent, further dissolving is inhibited until the random movement or diffusion process brings the solute particles in contact with further solvent particles. Clearly, temperature assists this since at higher temperatures the particles have higher kinetic energy and therefore could move more freely and quickly. The effect of stirring also increases the rate of dissolving further by moving undissolved solute particles more

quickly away from the surrounding particles of the solution and into contact with solvent particles. Therefore, the only factors which affect the rate at which sugar dissolves in water is speed of stirring (option A) and the temperature of the water used (option D). Hence there is no answer key to this question, with the given choices.

Question 8 (Level: P6)

The pictures below show two men getting a similar drum of oil onto a lorry.



a) Who is using less energy?

The man _____

(1 mark)

b) How do they both get their energy to do what they are doing?

_____

(2 marks)

Intended Answer:

(a) the man who is using a ramp

(b)They both get their energy from the food they eat.

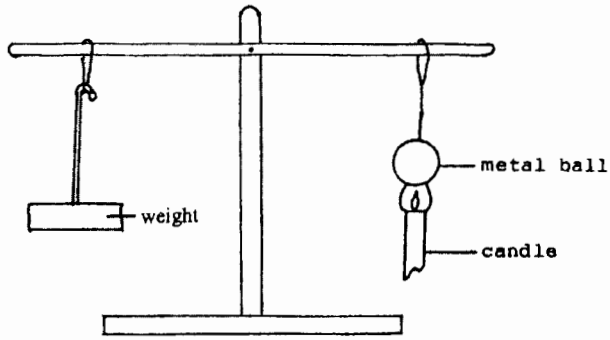
Comments

The question setter's answer to part (a) reveals a confusion of the concept of "energy" with the concept of "force". The energy required to lift an object is simply a product of mass (say, m) and height lifted (say, h) and the constant g, acceleration due to gravity (i.e., mgh). The man who is using a ramp is applying a smaller force (compared to the man who is not using a ramp) to move the drum of oil (the load) onto the lorry but this smaller force has to move over a longer distance, i.e., the length of the ramp (whereas the other man while having to exert a bigger force to lift the load, moves the load over a shorter distance (the vertical height between the ground and the back of the lorry)..

Thus the word 'energy" in part (a) of the question should be replaced with the word "effort". Thus the question (a) would read "Which man is using a smaller effort?" Then the answer to the question would be "The man who is using a ramp." Whilst the answer to part (b) is correct, a better question for part (b) would be: Give reason(s) for your answer to (a) above. In other words, the pupil should be probed for the thinking behind his/her answer in part (a) instead of merely choosing either one of the two cases as his/her answer.

Question 9 (Level: P6)

The diagram below shows an iron ball balanced with a weight. A candle flame is placed below the iron ball.



(a) Which of the following will happen after a few minutes? (1m)

Put a tick (✓) against the correct answer.

( ) The iron ball will go up while the weight will go down.

( ) The iron ball will go down while the weight will go up.

( ) Both the iron ball and the weight will remain in the same position..

(b) Give a reason for your answer. (1m)

_____

_____

Intended Answer:

(a) Both the iron ball and the weight will remain in the same position.

(b) Heating results in expansion of the metal ball but no change in weight.

Comment

This question does not really suggest any misconception on the part of the question setter but does indicate application of single factor reasoning to what in practice may be regarded as a multi-factor scenario. It has been selected for discussion here because of its resemblance to the PSLE (Primary School Leaving Examination) science question that had been raised and discussed at the Straits Times Forum in mid-October this year. The intended answers indicate a narrow range of reasoning on the part of the question setter whereas each of the other two options could be acceptable as the answer depending upon the extent to which other factors than simply the application of heat are taken into account. In the set-up depicted, since the heating is done with a candle flame, and with the candle flame contacting the metal ball, some pupils who look at this problem laterally may consider that the soot (one of the products of combustion of candle wax) that will inevitably be deposited on the metal ball will increase the weight of the iron ball sufficiently to cause it to go down and the counter-weight go up. It is also possible that some other pupils may consider the effect of convection currents (due to the hot gases produced in the candle flame) and choose the first option "the iron ball will go up while the weight will go down" as the best answer. This question illustrates the advantage of open-ended questions over the multiple choice questions (MCQs) in terms of the provision for the pupil to present his/her reason for choosing a particular option as answer. This, however, will only be true if the marking scheme for this type of open-ended question is broad and flexible enough to accommodate a range of acceptable answers- such as in this case when all three options in part (a) could be considered correct if the accompanying answer to part (b) is reasonable and valid (such as presented here).

Conclusions

The illustrative test items presented in this paper suggest that some teachers are weak in their own understanding of the science concepts that they are teaching. This is disadvantageous to pupils on two counts. Firstly, these teachers will be passing on erroneous concepts that may seriously impede the pupils' further learning of science. There is a significant body of research (e.g. Driver et al., 1985; Duit, 1991; Eaton, 1984; Palmer, 1999) indicating that misconceptions, once internalized, are very difficult to overcome. Secondly, even if the pupil has overcome the difficulty by, for example, consultation with a parent or private tutor, the pupil will likely be marked wrong for not matching the model answer. It should be expected that teachers, regardless of which disciplines they are teaching in, have mastery of their subjects at the level they are teaching.

The discussion of the nine questions also highlight the fact that where MCQs are concerned, it is challenging to craft stems and options in such a way that there is one and only one unique answer key. The challenges of using traditional MCQs in formal primary science assessment have been discussed elsewhere (Boo, 2002, 2003a,b; 2004a, b) and serve also to highlight the need for the use of a modified two-tier MCQ (Boo, 2003b, 2004a,b) in order to test pupils' higher order and lateral/creative thinking abilities.

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Annex 1

Read each statement below and circle 'A' if you agree with the statement and 'D' if you disagree with it.

A or D 1. Respiration is breathing.

A or D 2. In the lifecycle of a flowering plant, the seeds develop **before** the fruits.