Primary science assessment item setters' misconceptions concerning the state changes of water

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Contents

Brief Description

This paper considers a number of misconceptions concerning the state changes of water that can be conveyed through poorly crafted multiple-choice questions (MCQ) or test items.

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 these 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 primary science question setters' misconceptions concerning the state changes of water. It is based on a scrutiny of more than 100 sets of primary science examination papers. 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' conceptions or interpretations of scientific phenomena. A diversity of terms has been used to describe these students' ideas and conceptions. The terms ‘alternative conceptions’ have been generally accepted and used rather extensively in the literature (Pfundt & Duit, 1998; Wandersee, Mintzes & Novak, 1994) to describe misconceptions or views of science that are at odds with concepts currently accepted by the scientific community and these terms are used synonymously in this paper as in Boo (1998) and Boo and Watson (2001).

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 and 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 (for example, Pfundt and Duit, 1998; Carmichael et al., 1991).

That children and students hold various alternative conceptions concerning water and its state changes have been reported in studies such as Johnson (1998a,b); Bar & Travis (1991); Osborne & Cosgrove (1983). That teachers and student teachers also hold various misconceptions concerning physical science concepts have been reported in studies such as Lawrenz (1986) and Chang (1999) respectively. Some of these alternative conceptions are the same as those held by children and students (Wandersee, Mintzes & Novak, 1994).

The possible origins of ACs have been examined by many researchers. Among the sources of ACs suggested are misconceptions held by teachers and student teachers (Osborne and Cosgrove (1983); Bar and Travis (1991); Griffiths and Preston (1992)).

In this paper, teacher's apparent misconceptions in the area of the state changes of water as revealed in test items set by the teachers are discussed. Assessment items have been provided through a number of avenues over a period of more than five years: 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 ([Singapore] National Institute of Education) in-service courses for primary school teachers. 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 2001 for P3 (Primary 3; the first year in primary school during which science is formally studied as a subject) and progressively introduced into the schools with full implementation completed at P6 (Primary 6) in 2004. The grade level of each question is indicated for each test item discussed: P4 (Primary 4) or P5 (Primary 5) – mainstream – corresponding to pupils aged 10-11. Primary school in Singapore covers six years (P1 to P6), corresponding to pupils aged 7-12.

Misconceptions Concerning State Changes of Water

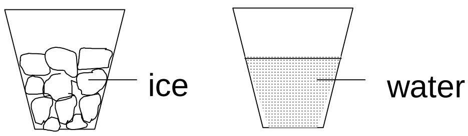
In Singapore, the subject of state changes and related heat transfers is introduced to pupils at the P4 level. The key concepts taught are the three states of matter, the state changes of freezing/melting and boiling/evaporation/condensation with understanding of the differentiation between evaporation and boiling.

The concepts involved are a recurrent source of problems to many question setters as illustrated by the following test items.

In example question 1 which contains three generic statements about ice and water, the intended answer is option (4) indicating that all three statements given about water and ice are true.

Example Question 1 (P4)

Look at the diagrams below carefully.



Which statements below are correct?

A) Ice melts to form water.
B) Water freezes to form ice.
C) The temperatures of ice and water are different.

1) A and B only 2) A and C only

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

However, statement C is problematic since ice and water can both exist at 0°C. Pupils should have been taught that the temperature of ice, for example brought out of the freezer at (say) -10°C, will gradually rise until it reaches the melting point, 0°C, and then remain constant until all of the ice has melted after which the temperature of the water will begin to rise until it attains the ambient temperature.

This item was improved by re-wording statement (C) as:

(C) The temperature of ice and water are always different and then making option (1) the answer key.

Example question 2[1] shows the same misconception in terms of the process of freezing.

[1] The question need not refer to pressure since the effects of pressure on state changes are outside the scope of the current Singapore primary science syllabus.

Example Question 2 (P4)

When water freezes, there is a decrease in _____.

1 temperature

2 state

3 volume

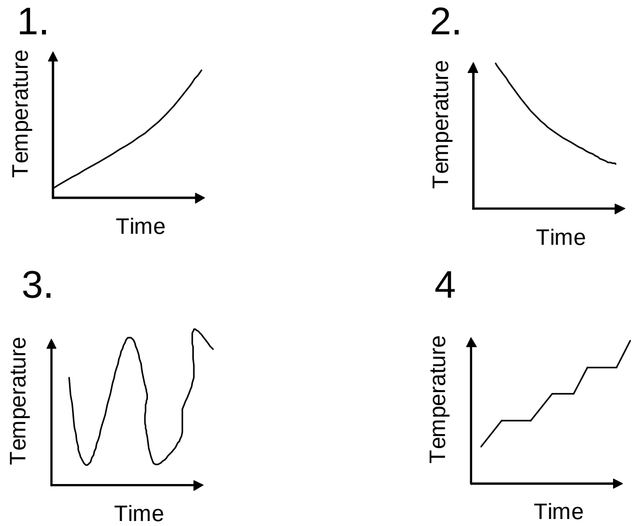
4 substance

Again, pupils will have been taught that when water changes to ice, the temperature remains constant at 0°C until all of the water has turned to ice. It may be that in, crafting the question, the question setter is thinking at an ‘everyday’ level of filling an ice cube tray with water from the tap at 25°C (in Singapore), putting it in the freezer and then the following morning taking out ice cubes at -10°C. It is important that pupils understand that, in science, words have a very precise meaning and that meaning may be different to the generally used meaning in everyday circumstances. In science, ‘freezing’ refers specifically to the changing of liquid to solid at the freezing point temperature.

Whilst example 2 may have been a matter of imprecise item crafting, the same cannot be said of example 3 where the question setter's understanding is explicitly indicated by intended answer of option (2) showing a fairly constant rate of temperature decrease throughout the time the beaker of water is left in the freezer and changed to ice.

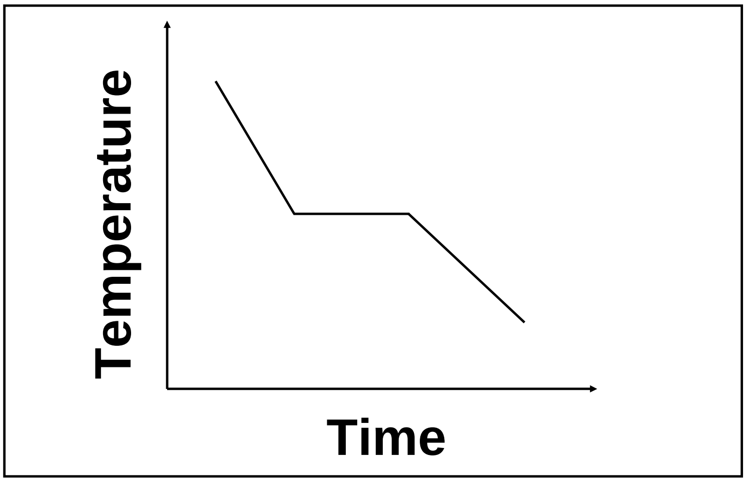
Example Question 3 (P4)

A beaker of water is left in the freezer. Which of the following graphs shows the change in temperature with time?



Whilst, at the primary level, pupils are not taught the detail of latent heat, they are provided with the understanding that temperature remains constant whilst freezing takes place and should have seen the correct generic graph illustrated in Figure 1.

Figure 1: Generic Graph for Freezing



In example question 4 we see the question setter exhibiting a very narrow understanding of the range of changes that are taking place with water at 0°C.

Example Question 4 (P4)

Which of the following changes takes place at 0 °**C** ?

(1) Ice to water vapour

(2) Water to ice

(3) Water vapour to water

(4) Water to water vapour

The intended answer is option (2) indicating that, as far as the question setter is concerned, freezing is the only change that might be taking place. In fact options (2), (3) and (4) are all correct[2]. Many question setters have the misconception that some minimum temperature is required before evaporation can take place. In fact, evaporation will take place from the surface of a liquid at all temperatures in the liquid phase (Option 4). The effect of temperature is to affect the rate at which evaporation will take place. Evaporation occurs even when liquid water is at 0°C. Water vapour can condense at any temperature, even when the water vapour is at 0°C; hence option (3) is also a possible answer.

[2] Whilst Option 1 is also true (sublimation also occurs), the concept of sublimation is outside the scope of the current Singapore primary science syllabus.

Example questions 5 and 6 illustrate similar misconceptions and item crafting problems concerning the process of boiling. The question setter's intended answer to question 5 is option (1). By including statement D, the question setter is exhibiting the misconception that steam and water are at different temperatures. However, when water boils at 100°C, the steam produced is also at 100°C[3].

Example Question 5 (P4)

Steam is different from water because ______________.

A. they are different in colour

B. they are different in size

C. they are different in state

D. they are different in temperature

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

In this question, pupils may have difficulty with not including statement B in their answer having been taught that liquids have a definite volume whereas gases do not.

Example question 6, where the intended answer is option (2), shows a similar misconception to the one seen in questions 2 and 3: the misconception that state change is always accompanied by temperature change; in this case, when a liquid boils there is a rise in temperature.

[3] The effects of pressure on state changes are outside the scope of the current Singapore primary science syllabus.

Example Question 6 (P5)

When water boils, there is a change in_______________.

A. Shape
B. Temperature
C. State
D. Water level

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

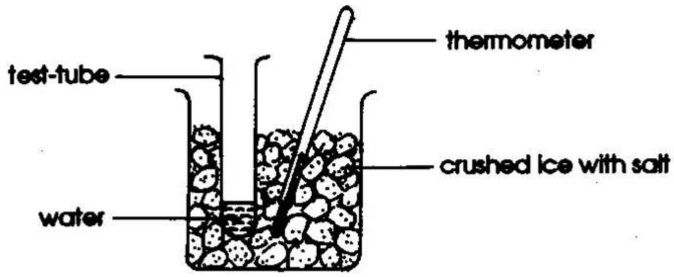
The intended answers suggests a conception that, at the boiling point, the water is at 100°C whilst the steam produced is at a temperature greater than 100°C. However, as with question 2, the problem may be one of item crafting and the dominance of everyday thinking in the use of language. When we say "boil the water to make some coffee" what we are describing is the process of raising the temperature of the water from room temperature to boiling point. If we then continue to apply heat, for example by not switching off the heat source, then the water will boil and steam will be produced. It is important to emphasise that when a scientist talks of boiling he specifically means the change from liquid to gas at the boiling point temperature. Steam, if contained, can be further heated to even higher temperatures.

Many question setters are unclear about the precise details associated with adding a solute to ice or an ice/water mixture.

Example question 7 illustrates a typical question setter's misconception on this matter.

Example Question 7 (P4)

What is most likely to happen in the following set-up?



(1) The water turns in to 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

In this example, option (1) is the intended answer. However, in practice this outcome may not occur. It all depends upon the amount of salt added to the crushed ice. The misconception is that any amount of salt will sufficiently lower the temperature of the crushed ice to cause the water in the test tube to freeze. In fact, the desired effect is related to the mole fraction (amount) of added salt up to the eutectic point. The origin of this misconception may be the result of teachers simply repeating a workbook experiment with a single quantity of salt and observing a lowering of the freezing point of the ice and then not experimenting further with different amounts of salt to reveal the cause-effect relationship between the amount of salt added and the resultant freezing point of the ice-salt mixture. Whilst the relationship between the amount of salt added and the lowering of the melting point of ice and the term eutectic point are not explicitly introduced in the primary syllabus, it is important that teachers avoid introducing alternative conceptions at this level since these could form resistant barriers to further learning at a later stage. Of the options provided, option (2) is the only one that we can be sure will take place whatever the amount of salt added to the crushed ice. This was certainly not the intended answer that the question setter had in mind and further illustrates the misconception concerning evaporation discussed under Example Question 4 that some minimum temperature is required before evaporation takes place. A further problem with the question as presented is that the quantity of ice may be high enough and/or its temperature low enough to cause freezing of the water in the tube even without the addition of salt.

A variant of the misconception concerning the addition of salt to ice is shown in example question 8.

Example Question 8 (P4)

When salt is added to ice, what is the most likely temperature range of the mixture?

1. between –10 °C to -8 °C.
2. between –8 °C to -3 °C
3. between –3 °C to 3 °C.
4. Above 10 °C.

The setter's intended answer is option 1 indicating the misconception that the decrease in the temperature of the ice is independent of the amount of salt added – i.e. that any amount of salt, however small or large when added to ice will produce this very narrow temperature range. In fact, depending upon the amount of salt added the temperature could fall to as low as -20°C. This question would be better re-crafted as a free response item asking pupils to describe the effect of adding salt to crushed ice.

Discussion

The example assessment items discussed in this paper demonstrate some of the misconceptions perpetuated by teachers and question setters concerning basic physical science phenomena:

- Confusion between the everyday use of terms such as freezing and boiling and the scientific use of these terms;
- The processes of freezing, melting and boiling involve a change in temperature;
- Water and ice cannot exist at the same temperature;
- Water and steam cannot exist at the same temperature;
- The narrow range of understandings in any given situation, for example, not recognizing that evaporation of water and melting of ice take place simultaneously at 0°C;
- Evaporation of water requires the body of water or the surrounding air to be at some minimum temperature;
- When salt is added to crushed ice surrounding a test tube containing a small amount of water, the resultant lower temperature in the ice-salt mixture is always low enough to cause freezing of the water in the test tube;
- When salt is added to crushed ice then there is a fixed drop in temperature irrespective of the proportion of salt in the mixture.

Whilst some of the misconceptions may be due to poor item crafting - particularly the failure to see all the possible perspectives that the pupils might see, it must be assumed that many of them are deeply held and will therefore be reflected in classroom instruction. This would support the suggestion by many researchers that teachers can be the source of many of the misconceptions held by pupils.

Many in-service teachers at the primary level either do not have a science background or are only practising 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 through the standard experiments that demonstrate the key science concepts that are giving problems to some teachers. For example they could carry out temperature recordings through state changes and be convinced that freezing and boiling take place without change in temperature.

Poorly crafted assessment items not only invalidate the assessment process but disadvantage pupils, 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 question setter but who have no means in an MCQ to convey their understanding. Because of the authoritative nature with which assessment items are regarded, such items may either reinforce already held misconceptions amongst pupils or, worse, introduce misconceptions where previously correct conceptions were held.

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 options of the MCQs. Quality review is particularly important in the case of MCQs which provide no means for the pupil to express alternate ideas to those held by the question setter 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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