# Alternative approaches to science assessment

## the Victorian experience

Brian Doig
The Australian Council for Educational Research

The 1990 Victorian Science Achievement Study was a survey of science learning undertaken by the Australian Council for Educational Research at the request of the Victorian Department of School Education. The key aims of this study inter alia were to survey student performance with respect to the broad range of learning goals specified by current curriculum guidelines, to report on the full range of student performance rather than minimum competence and to develop resources that could be used by teachers as part of their own assessment practices.

Research undertaken over the last decade or so which has revealed that children construct their own unique and rational conceptions of natural phenomena. As Osborne and Freyberg (1985: 13) point out:

‘Children naturally attempt to make sense of the world in which they live in terms of their experience … It is these ideas that we call children’s science. it is the similarities and differences between children’s science and scientists’ that are of central importance in the teaching and learning of science.’

Further, when children’s conceptions are at odds with currently accepted scientific concepts there are several possible outcomes from a learning situation:

- the concept may be ignored;
- the concept may cause confusions which are not resolved;
- the concept may be misinterpreted and made to fit the child’s concepts;
- the concept may be used for ‘school’ science and not applied generally;
- the concept may become fully integrated into the child’s conceptual schemes.

(after Gunstone, 1990)

(For a detailed explanation of this research the report of the Victorian Science Achievement Study (Adams, Doig and Rosier, 1990) should be consulted.)

If teachers do not determine children’s understandings and beliefs they cannot be challenged, so it becomes imperative that teachers know the current beliefs held by their students. The methods that are generally used to explore student conceptions require one-to-one interactions between an interviewer and an interviewee. In the Victorian study a desire to assess some 3000 students made this technique impossible and so an attempt was made to emulate interviews through written instruments which used 'real-life' situations and role-playing. Since the intention was to draw out the underlying beliefs that children hold with respect to various aspects of science, the assessment instruments collectively entitled units for Tapping Students’ Science Beliefs (TSSB) were developed with this

focus. What each TSSB does is assess the beliefs students have about a certain natural phenomenon and permits appropriate learning experiences to be planned. The fact that results from this approach are similar to that of previous interview research would indicate a degree of success in this emulation.

As with all surveys of this type it was not possible to consider all aspects of the curriculum, thus a selection of key topics was selected for investigation. Five thematic units were developed to provide students with the opportunity to express their conceptions (or beliefs) about science related phenomena. The five individual TSSB units are:

Skateboard News

This is a newsletter which discusses aspects of skateboards and skateboarding. It focusses on tapping children's conceptions of force and motion, with a special emphasis on aspects of gravity and its effects.

What Happened Last Night

In this short story about a child and an alien from space, the reader answers the alien's questions about the Earth and other celestial bodies. The story focusses on the Earth in space and on tapping children's conceptions of gravity, night and day, and the differences between the Earth and the Sun.

The Day We Cooked Pancakes at School

In this cartoon the two student cooks wonder about the changes happening to their mixture. The reader is asked to offer reasons for the changes. This story focusses on tapping children's conceptions of the structure of matter, with particular emphasis on children's awareness of the particulate model.

Children's Week

This is a role play based on the idea of the reader being 'Teacher for the day' during Children's Week science lessons. Some questions being asked by the children are provided to give the reader some practice. The focus is on tapping children's conceptions of light and its properties, and the processes of sight.

Our School Garden

This is a cartoon about two children cleaning up part of the school yard to make a vegetable garden. Several times during the clean up, the children argue and puzzle over what is happening. The reader is asked to comment. The focus is on tapping children's conceptions of living things.

The TSSB units were administered to some 1400 year 5 students and some 1200 year 9 students. The same set of TSSBs were administered to both years, with each student responding to two units. At the completion of the data collection, student responses were coded. The coding of responses was of particular concern because a number of authors have argued that conceptions are unique since they are the result of personal theorising and hypothesizing which lead to idiosyncratic representations of the physical world (Trowbridge and Mintzes, 1988; Gilbert and Watts, 1985). Others however have noted that while the number of alternative conceptions may possibly equal the number of individuals, the conceptions may be classified into a smaller number of mutually exclusive notions or categories (Nussbaum

and Sharoni-Dagan, 1983). A coding scheme was developed that placed each student's written or illustrated responses to TSSB questions into one of a small number of mutually exclusive categories. These categories were developed using the combined evidence of previous research, trial data and an investigation of the responses received in the actual data collection. At a second stage of analysis, the categories were assigned integer levels. That is, within each stimulus, the qualitative response categories were ordered with respect to their sophistication, or naivety, when judged against current scientific thinking. These level indicators cannot be compared across questions and in many cases two or more qualitative responses were assigned to the same level. Finally, these levels of response were analysed using the Rasch Partial Credit Model (Wright and Masters, 1982). The use of this statistical model made possible the construction of a developmental continuum for each TSSB unit. These continua form the basis of the descriptors used to assess student's levels of conceptual development which form the individual and group profiles discussed later in this paper.

The Victorian study also produced data to support other research which shows students holding a range of science beliefs that may interfere with their science learning. In addition the study also identified some beliefs that had not previously been reported. Complete details of these and the other findings of the study are contained in the full report (Adams, Doig and Rosier; 1991).

To fully understand the TSSB style of assessment, it is best to work through an example. The unit selected as an example is The day we cooked pancakes at school, which investigates student beliefs about the nature of matter and chemical reactions. Specifically this unit explores whether students spontaneously use the particulate model to describe the structure of matter, to illustrate changes in state, and explain processes such as dissolving and condensing. In addition students' beliefs about chemical changes that result from burning and cooking are explored, as well as their beliefs about conservation of matter.

'In modern science, the fundamental notion that all matter is particulate and not continuous is of prime importance for all causal explanations of

any kind of change in matter'
(Nussbaum, 1985: 124)

The particulate model is based upon assumptions that are beyond direct observation and it is not surprising, therefore, to find that many students have difficulty adopting the model as an explanation of the observed behaviour of matter. Further, the particulate model is unlikely to be consistent with the beliefs that students develop from their own observation. Even those students that appear accept the particulate model, adapt it in idiosyncratic ways (Driver, 1985).

Research by Osborne and Cosgrove (1983) has shown that while students are capable of using appropriate terminology such as; 'evaporation', 'condensation' and 'melting', to describe chemical and physical changes, it is unusual for them to hold the underlying scientific concepts. This unit encourages students to provide diagrams and extended explanations to expose

their underlying beliefs.
In order to score a student's responses to the Pancakes unit, it is necessary top follow the scoring scheme set out in the tables below. These tables provide the criteria for scoring this TSSB unit. The responses to each item are classified into categories and the first column of the tables indicate the score for the category and an identifying label. The second column describes the characteristics of a response that should be placed in that category, and in some cases the third column provides illustrative responses. For some items a recommended strategy for scoring follows the tables. In addition to the categories described in the tables there are three additional response categories available for every item. These all have the same score value:
Score 0 Response does not address the question, restates the question, is uninterpretable or an 'I don't know'.
Score 0 No response was made to the item.
Score 0 The response was not anticipated by the scoring criteria.

Item 1 Structure of a solid
Purpose: To determine if students spntaneously acknowledge the existence of a finer structure in matter – a structure that could not be observed with the naked eye.
Score LabelDescriptionExamples1 ParticulateThe response indicates that flour is made up of smaller particles. The particles may be cellular, molecular or atomic.
0 ContinuousThe response did not include an attempt to represent a structure beyond that which could be directly observed. This response is most typically simple 'dots' or 'blobs'.

Additional Notes
This item is quite difficult and only the very best students will produce a particulate type response.
Some students may draw a close up view of an ear of wheat. These responses should be scored as 0.

Item 2 States of matter
Purpose: To explore the way that students would choose to represent the distinction between different states of matter.
Score LabelDescriptionExamples4 Particulate
The response indicates that solids, liquids and gasses are made up of smaller particles. The state is determined by the arrangement of these particles.
3 Continuous
The response provides an abstract representation of the states of matter but does not use the particulate model. Typically the response will

include a solid block or cube, a vessel containing water and whispy lines or scattered dots for a gas.

2 Properties

The response focusses on the properties of matter in different states, such as hardness of a solid, fluidity of liquids and the lightness or invisibility of a gas.

1 Examples

The response provides examples of a solid, a liquid, and a gas. For example, a water tap to indicate a liquid and a balloon to reperesent a gas .

Item 3 Dissolving

Purpose: To determine how students explain the process of dissolving; specifically can students apply the particulate model to explain the process of dissolving.

Score LabelDescriptionExamples2 Suspended particulateThe response use the particulate model to explain how the particles of sugar can become suspended in between the particles of the liquid.

1 InvisibleThe response indicates that the grains of sugar becomes so small that we can't see them. Such responses will often indicate a temporal process – the sugar grains gradually becoming smaller over time.

0 Mixes inThe response simply states that the sugar mixes in. There is no explanation of the mixing process that blends the sugar and liquid.

0 DisappearsThe response clearly indicates that the sugar finally disappears as if by magic. In these responses the student clearly indicates that the sugar has 'gone'.

Additional Notes

The key distinction between the Invisible and Disappears responses is that the Disappears response corresponds to the total disappearance of the sugar (as if magically it has gone). In contrast, the Invisible response involves the particles becoming so small that they cannot be seen. Responses which indicate that the sugar ends up on the bottom of the glass should be scored 0.

Item 4 Change of state

Purpose: To determine how students explain changes of a substance from one state to another. In this case ice becoming water.

Score LabelDescriptionExamples3 Particulate

The response clearly states that change of state results from a change in the arrangement of particles. Added energy in the form of heat causes the particles to re-arrange.

2 Particulate (incomplete)

The response indicates that water and ice are the same substance. The

particulate model is used to illustrate the distinction but the rôle that heat plays in the change is not explained.

1 Heat and state

The response indicates that water and ice are the same substance but in different states and that heat causes change from one state to the other. There is no indication of the particulate model as an explanation.

Additional Notes

Use both parts of the question to determine the score.

To say that heat melts the ice into water is a simple restatement and should be scored as 0, whereas a score of 1 should be given to responses stating that water and ice are the same substance but heat causes ice to change to water.

A response that indicates that heat effects the way the molecules 'hang together' distinguishes a score of 3 from a score of 2.

Item 5 Condensation

Purpose: To determine how students explain condensation; specifically can students apply the particulate model to explain the process of condensation?

Score LabelDescriptionExamples4 ScientificThe response indicates that condensation occurs when the air temperature is decreased and it is clear that the water on the outside of the jug has come from the atmosphere.

3 CondensationThe response uses the word condensation or says that the water comes from the atmosphere but no cause or mechanism for condensation is provided.

Condensation on the side of the jug.

From the atmosphere.

2 ColdnessThe response states that condensation is caused by coldness or it is made by the ice. There is no indication that the liquuid has come from the atmoshpere.

From the ice.

The coldness makes it frost.1 From the jugThe response suggests that the water has come from inside the jug.

From the water inside the jug when the ice melts.

0 Through the jugThe response indicates that the water has actually come through the side of the jug.

It's coming through little cracks in the jug.

Additional Notes

A number of students indicate that the ice melts and this overflows the jug. Score these response as 0.

The distinction between from and through is sometimes subtle. Use 0 only if it is clear that the student suggests that the water passess through the jug.

Item 6 Conservation of matter
Purpose: To determine how students perceive chemical reactions and their awareness of the conservation of energy.
Score LabelDescriptionExamples2 ConservationThe response gives the products of burning as heat, gas, and ash with a supporting description of the weight of the products.
1 Ash and gasThe response gives only the substantial products ash and gas while ignoring heat and light. There is a plausible description of the weight of the products.
0 MagicThe response suggests that burning uses up the match. Some of the match has magically disappeared.
Additional Notes
Use both parts of the question to determine the score.
Some responses indicate that some ash will have fallen in the bin. This should be scored 0.

Item 7 What's in a bubble?
Purpose: To determine whether students regard heat as a substance.
Score LabelDescriptionExamples3 Heat expanded gassesThe response indicates that the bubbles are made from hot air and, or, gasses that were in the mixture and have been expanded by heat.The air inside the pancake. When the pancake is heated the air expands and blows into a bubble.
2 HeatThe response indicates that bubbles are made of heat. The response indicates that the student sees heat as a substance.From the heat trying to get through the pancake. They will disappear when the heat has gotten through completely.
Air and heat.
1 Unexplained gassesThe response suggests that bubbles are made of air or gas but no mechanism is given.Oxygen and air gasses.
The air from inside the mixture when it was beaten up.
0 Other substancesThe response indicates bubbles are made from some of the ingredients of the pancake.
The butter and oil mixed in.

Item 8 What cooking does
Purpose: To determine how students would describe the changes in the mixture that are caused by cooking.
Score LabelDescriptionExamples3 Chemical ReactionThe response indicates that cooking causes a chemical reaction and the molecular structure of the mixture is changed.
Instead of being a mixture, from which you could evaporate substances it is a 'compound' which can't be broken up into what it was before.
2 MixesThe response indicates that cooking has caused the ingredients to

mix together. The cooking causes some kind of change but an explanation for that change is not provided.
The heat has caused it to change into a solid.
1 Liquids removedThe response indicates that cooking dries out the mixture. The only change caused by cooking is the removal of liquids.
Dried it out.
Evaporated out all of the water.0 Changes tasteThe response suggests that all cooking does is change the taste, but no description of the change or reasons for the change are provided.
Cooked the ingredients. Brought the flavour out.
When it gets hot it gets tastier.

Item9 Evaporation
Purpose: To determine student awareness and understanding of evaporation.
Score LabelDescriptionExamples2 Evaporates (qualified)
The response indicates that the water on the dishes has evaporated and that evaporation is the process whereby the water is stored in the air as vapour.
It is evaporated into the air where it is carried as water vapour.1 Evaporates
The response uses the term 'evaporates' but does not have a complete explanation of the process. Some responses of this type suggest that evaporated water turns into air.
It evaporates into the atmosphere.
Turns into air.0 Disappears
The response indicates that there is a magical disappearance of the water.
0 Absorbed
The response indicates that the water is absorbed into the dishes.
It goes into the clay of the cups.
In the dishes.
Additional Notes
Use both parts of the question to determine the score.
Responses that indicate the remaining water is dried with a towel or goes down the drain should be scored 0.

Each of the TSSB units has its own Student Score Sheet. A copy of the relevant score sheet for this unit can be found also in Appendix A.
Each TSSB Student Score Sheet has two major sections. The first of these is on the left-hand side and the matrix here deals with the recording of student scores for each question of the TSSB. The right-hand side contains the appropriate TSSB continuum and its associated descriptions.
The scoring matrix sets out each question of the TSSB with a description giving the emphasis of the question. This matrix also contains the possible scores associated with each question. Within each TSSB the questions do not have the same number of score points. At first this may

seem strange, but a glance at the scoring criteria for different questions soon reveals why this is so. Thus, in order to better reflect a student's level of response, the scoring boxes have been arranged so as to align both the lowest and highest scores (that is, the least and most sophisticated levels of response). This means that the scores in between are not necessarily aligned.

These scoring criteria should be used to score the (real) student responses to be found in Appendix A. The actual score is recorded by crossing or circling the number in the appropriate cell of the scoring matrix. The total score can then easily be calculated. Below the scoring matrix is a space for recording this total score.

The TSSB continuum on the right-hand side of the Student Score Sheet is where the student's total score may be visually described by marking the scale with a cross at the appropriate position. This will make reading the relevant TSSB description easier.

Once this has been done a Student Score Sheet is complete. A completed Student Score Sheet is shown below.

Individual TSSB profiles

Once a Student Score Sheet has been completed an individual student profile may be constructed. The purpose of such a profile is to assist in readily identifying a student's main strengths and weaknesses. An individual profile is created simply by joining with lines the scores for that student. This gives an immediate indication of a student's position relative to the most sophisticated response for each question.

In the example below, the score for question four is based upon an unsophisticated response. It is clear that question four has revealed a weakness in the student's understanding of the nature of moonlight. Reference to the the scoring criteria for this question reveals that this student has no awareness of the moon reflecting sunlight. By comparison, the responses to many of the other questions have demonstrated a more sophisticated understanding of the aspects of science addressed by this TSSB.

The Student Profile for the student whose responses were scored earlier should be completed as indicated. Although the construction of an individual profile is trivial, the insights gained of student understandings, both naïve and sophisticated, are extremely valuable. The profile is, of course, based upon the responses given to the questions within a particular TSSB and this may limit the usefulness of the profile if one does not also take into consideration other aspects of the student's work in science, such as their results from other assessements, their class work and so on.

INSERT REAL RESULTS DISCUSSION HERE.

Although TSSBs are not achievement oriented a student's conceptual development may be observed by re-assessment and comparison of their profiles over time. It must be borne in mind though that conceptual

development is not simply a matter of continuously becoming more sophisticated, but rather may be quite haphazard with newer information not yet completely accommodated by the student's conceptual framework. Any subsequent re-assessment which shows deviation from increasingly more sophisticated performance does not necessarily indicate a worsening situation, but rather may indicate the natural process of concept development and refinement.

Adams, R. J., Doig, B. A. and Rosier, M. (1991). The Victorian Science Achievement Study 1990. Hawthorn: The Australian Council for Educational Research.
Driver, R. (1985). Beyond Appearances: The conservation of matter under physical and chemical transformations. In R. Driver, E.Guesne, A. Tiberghien (editors). Children's Ideas in Science. Milton Keynes: Open University Press.
Gilbert, J. K. and Watts, D. M. (1985). Force and Motion. In R. Driver, E.Guesne, A. Tiberghien (editors). Children's Ideas in Science. Milton Keynes: Open University Press.
Gunstone, R. F. (1990). 'Children's science': A decade of developments in constructivist views of science teaching and learning. The Australian Science Teachers Journal, November, 36 (4), 9-19.
Nussbaum, J. (1985). The particulate nature of matter in the gaseous phase. In R. Driver, E.Guesne, A. Tiberghien (editors). Children's Ideas in Science. Milton Keynes: Open University Press.
Nussbaum, J. and Sharoni-Dagan, N (1983) Changes in second grade children's preconceptions about the Earth as a cosmic body resulting from a short series of audio-tutorial lessons. Science Education, 67(1), 99-114.
Osborne, R. J. and Freyberg, P. (1985). Learning in Science: The implications of children's science. Auckland: Heinemann.
Osborne, R., and Cosgrove, M.M. (1983). Children's conceptions of the changes of states of water. Journal of Research in Science Teaching. 20(9), 825-838.
Trowbridge, J.E. and Mintzes, J.J. (1988). Alternative conceptions in animal classification: a cross age study. Journal of Research in Science Teaching. 25(7), 547-571.
Wright, B. D. and Masters, G. N. (1982). Rating Scale Analysis. Chicago: MESA Press.

APPENDIX A

Copies of the items contained in Appendix A may be obtained through inter-library loan from the Librarian, The Australian Council for Educxational Research, Post Office Box 210, Hawthorn, Victoria 3122.
The appropriate Student Profile sheet can to be found in Appendix A.
The method that was employed in the 1990 Victorian study is obviously usable in other areas too.