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# Methodological misconceptions: naïve or not interested?

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Ray Adams

The Australian Council for Educational Research
(Australia)

Paper presented at the Third International Seminar on
Misconceptions and Educational Strategies in Science and Mathematics

August 1 - 4
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# Methodological misconceptions: naïve or not interested?

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**ABSTRACT**

This paper discusses the limitations of current methodologies for exploring 'misconceptions' and offers an alternative methodology which integrates various levels of sophistication of conception to describe a continuum of conceptual understanding. This approach recently employed in science education at elementary and junior high school levels used novel instruments (cartoons and short stories) to collect data from some 3000 children. This data was analyzed with item response techniques and continua constructed which allow educators to plan effective instruction for learners whose conceptions cover a range of sophistication, many of which may impede further learning.

**INTRODUCTION**

There is now a strong view among learning theorists that students come to learning situations not as empty vessels to be filled with a set of knowledge, skills, appreciations and understandings, but as active learners who through their observations, experiences and interpretations have constructed explanatory systems that give meaning and coherence to the world about them. This view is strongly supported in science education by the extensive constructivist literature that provides evidence for the claim that students come to learning situations with well developed and intricate explanations for natural phenomena. Within this work the meaning systems that students construct have been variously called misconceptions (Helm, 1980), pre-conceptions (Novak, 1977), alternative conceptions (Driver and Easley, 1978), alternative frameworks, and children's science (Osborne, 1980).

'Children naturally attempt to make sense of the world in which they live in terms of their experiences, their current knowledge and their use of language...we are all scientists of a sort from a young age. The child-as-scientist develops ideas albeit tacitly, about how and why things behave as they do, which are sensible to the child. It is these ideas that we call children's science. It is the similarities and differences between children's science and scientists' science that are of central importance in the teaching and learning of science.' (Osborne and Freyberg, 1985: p13)

The common thread in this research is that student understandings are not viewed as minor misunderstandings or knowledge gaps but as robust, often highly integrated conceptual frameworks for the interpretation of natural events.

**TYPICAL METHODOLOGIES**

Many of the constructivist studies carried out in science education have a number of common characteristics. First they are interview based, that is data about an individual's conception are gathered through a one-to-one interaction between an interviewer and a student. In this setting a student can be stimulated with physical material and discussion, while the interviewer can follow cues in the student's activity and response to expose the diversity and complexity of the individual's conceptions.

Second, the studies focus on carefully defined domains; for example, Westbrook and Marek (1991) focus on student conceptions of diffusion, Bell (1982) considers student understanding of the word 'animal' and, Osborne and Cosgrove (1983) focus on changes in the state of matter to provide but a few examples from any extensive battery of studies.

Third, they produce lists or inventories of conceptions held by students. There is a wide variation in the amount of structure or coherence given to these lists by various researchers. For example, Nussbaum and Novak (1976) and Nussbaum (1979) have argued that childrens' beliefs about the earth, as a cosmic body can be broken into five basic notions: (1) the earth is flat, the sky is parallel to the ground and down is below the flat earth; (2) the earth is a huge ball made up of two hemispheres, the lower is the solid earth, and the upper is the sky. We stand on the flat top of the lower hemisphere, and we look up at a rounded sky; down is an absolute direction, common to every one; (3) the earth is round, like a ball, and surrounded by the sky. However, we can only live on the top, and the cosmos has a fixed, downward direction; (4) the earth is round, like a ball, surrounded by sky, and we can live anywhere on it, but there is an absolute down direction, or bottom to the cosmos; (5) compatible with current scientific conception.

A less structured framework is presented by Gunstone and Watts (1985) who provide a list of intuitive rules that students have been commonly found to use when explaining physical phenomena. These are: (1) forces are to do with living things; (2) constant motion requires a constant force; (3) the amount of motion is proportional to the amount of force; (4) if a body is not moving, there is no force acting on it; (5) if a body is moving, there is a force acting on it in the direction of motion.

Gunstone and Watts have been unwilling (or unable) to produce integrated descriptions of a small number of notions in the way that Nussbaum and Novak (1976) and Nussbaum (1979) appear to have found useful. This unwillingness to provide generalised frameworks may be due to the often expressed view that students conceptions are personal (Driver, Guesne and Tiberghien, 1985) or idiosyncratic and unique (Trowbridge and Mintzes, 1988).

The researchers who are working within the phenomenographic tradition hold a position that lies somewhere between the above approaches. The aim of phenomenographic research is to reveal the qualitatively different ways in which people experience, understand and conceptualise the various phenomena in the world around them (Marton, 1981). Phenomenographers believe that there is a limited number of different ways in which phenomena can be understood and the goal of their research is to produce descriptions of these. They do not however, believe that individuals hold fixed understandings but that conceptions displayed by specific individuals will vary with context. For example, Renström, Andersson and Marton (1990) use an 'outcome space'of seven broad notions to describe how individuals understand matter, but they show how the same individual may display different conception when faced with different substances.

'The students think about matter in relation to different questions, different problems and different substances and their understandings of matter vary accordingly. After all, the understanding of matter is always an understanding of matter in a particular context, and hence the differing understanding observed should be seen as relations between individuals and phenomena.'

(Renström, Andersson, and Marton, 1990: 567)

Each methodology has its strengths and weaknesses. The researcher's own philosophy and skills will, in the main, determine which approach is used. However, researchers who are planning large-scale data collection for more generalizable results, are poorly served by the techniques outlined above. Analytic techniques too are generally less well defined than one would want, although recent developments in the use of computers in qualitative research is beginning to redress this (Tesch, 1990). Further, the remarks of Renström, Andersson, and Marton cited above would indicate that deterministic models of student conceptual understandings are inappropriate. In the remainder of this paper we will outline a procedure that has the strengths of the naturalistic approaches cited above, and adds a strong theory-based probabalistic analytic technique which allows generalizability of results to a far greater degree than hitherto possible, and allows the integration of measures of student performance across seemingly disparate aspects of science.

## A CHALLENGE

In 1990 the Australian Council for Educational Research was charged by the Victorian Ministry of Education with the responsibility for surveying the status of science learning in Victorian schools. The Ministry wanted a sample size of some three thousand children and results were to be reported to schools and the wider community in a manner understandable to all.

In undertaking the task, our desire was to provide indicators of students' science achievements, but unlike many traditional surveys of science learning, we adopted the fundamental principle that our approach to assessment had to be consistent with current research in science education. This necessarily led to a 'constructivist' (Driver, Guesne and Tiberghien, 1985; Osborne and Freyberg, 1985) influence on our procedures. First a broad perspective of science learning was of concern, second a mechanism was required for reporting students' status with respect to broad domains of understanding, and finally we intended to construct a continuum which would describe the development of student understandings, thus integrating different aspects of these science understanding. Each of these issues presents problems in methodology for a large scale survey of science learning. In the remainder of this paper we describe our attempts to address each of these issues while being consistent with the view of learning that underpins a constructivist methodology.

## LATENT TRAIT MODELS

The class of statistical models that are commonly described as latent trait models appeared to be tailor-made for our research. The underlying assumption of some basic trait (such as science understanding in this case) combined with the possibility of reporting on both individuals and groups with more detail than mean scores and standard deviations give, made a latent trait approach extremely attractive. Comparing student ability with item difficulty through the use of a common scale means that both student diagnostic information as well curriculum issues can be addressed. Reporting too, can be simplified through the use of such formats as 'kidmaps'.

Of the available latent trait models, the Rasch model (Rasch, 1980) is perhaps the best known and would offer the facilities sought. However, the Rasch model is limited to dichotomous items and our intention to follow constructivist principles and our reading of similar studies in children's science, led us to the conclusion that a more sophisticated model was needed. The Partial Credit Model (Masters, 1982; 1988) as a tool for analyzing responses that form partially ordered categories seemed ideal given that the work of researchers such as Nussbaum, Novak, and phenomenographers such as Marton, suggested that conceptual development could be usefully categorized. Since our study work by Ramsden, Masters, Stephanou, Walsh, Martin, Laurillard and Marton (1993) in elementary physics suggests that our view that these assumptions were warranted.

**THE DEVELOPMENT OF INSTRUMENTS**

Our first step was to consider how it would be possible to explore students' conceptions in a survey format–we needed a written format that encouraged students to express their beliefs about a range of science concepts. The result of our attempt is a set of six units that we have called units for Tapping Students Science Beliefs (TSSB). Each TSSB focuses on an area of science learning and requires students to interact with a cartoon or a written story, generally by providing an extended written or drawn explanation for the observations or actions of characters within the story.

Figure 1 provides a brief description of each of the six TSSBs that were developed; it indicates the name of the TSSB, its content focus and the number of Year 5 and Year 9 students who responded to it. The content for each TSSB was decided upon after a review of relevant literature and consequently most items were specifically aimed to expose conceptions that had been previously identified in constructivist research studies.

Figure 1 The Units for Tapping Students' Science Beliefs

- THE DAY WE COOKED PANCAKES AT SCHOOL

A cartoon story that took students through the steps involved in making pancakes, asking them to comment on and explain the observations of the characters in the story by providing illustrated and written responses. The content focus of this TSSB was the structure of matter and it was administered to 538 Year 5 students and 458 Year 9 students.

- WHAT HAPPENED LAST NIGHT

A short story that is a conversation between a young child and an alien. The alien queries the child about the nature of the Earth, the Sun and the Moon and the student responding to the TSSB plays the role of the child by providing illustrations and written response to the alien's questions. The content focus of this TSSB was Earth in space and it was administered to 578 Year 5 students and 456 Year 9 students.

- SKATEBOARD NEWS

A psuedo-newsletter about skateboarding. In this TSSB students where shown illustrations of skateboards and skateboard riders in a variety of contexts and they were asked to provide written answers to questions that were asked about each illustration. The content focus of this TSSB was force and motion and it was administered to 559 Year 5 students and 479 Year 9 students.

- CHILDREN'S WEEK

Designed as an activity for children's week this TSSB encouraged students to play the role of teacher by providing, for younger students, explanations of various characteristics, features and properties of light. For stimulus a question was provided and answers given by a number of younger children were provided. The student then responded to the answers given by the younger children. The content focus of this TSSB was light and sight and it was administered to 543 Year 5 students and 466 Year 9 students.

- OUR SCHOOL GARDEN

A cartoon story that followed two children through the preparation of a small school garden. Students responded to the stimulus by, commenting upon, and providing explanations for observations that were made by characters in the story. The content focus of this TSSB was living things and it was administered to 544 Year 5 students.

- ENVIRONMENTAL IMPACT SURVEY

This TSSB was a role play that presented the results, and follow-up discussion, from an environmental impact survey undertaken by a class of students on a vacant block of land. The content focus of this TSSB was living things and their environment and it was administered to 486 Year 9 students.

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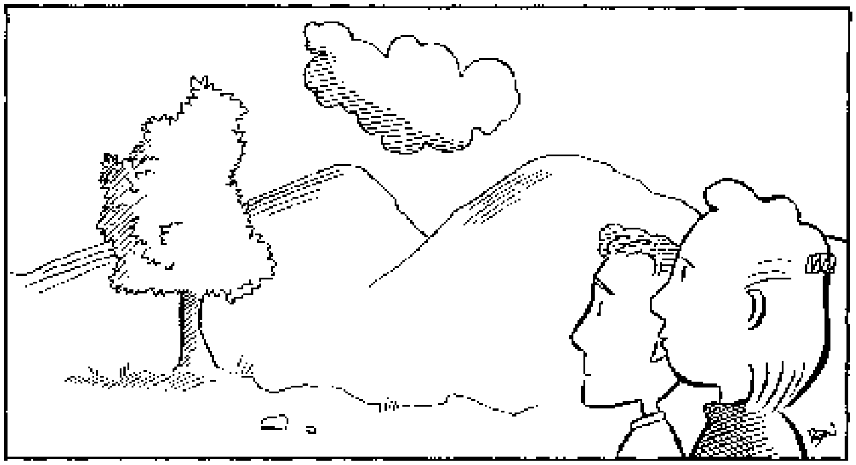
TSSB items were based where-ever possible on previous research. For example, Figure 2 shows an item from the Light and Sight TSSB that was developed from research by Guesne (1985) who has developed a four-fold classification for the way the students typically describe the process of vision.

To appreciate the style of the TSSB units Appendix A contains the entire suite of items from the 'The day we cooked pancakes at school' TSSB, which focuses on the structure of matter.

Figure 2 A Light and Sight Item



**DATA COLLECTION AND CODING**

For each item in the TSSBs a qualitative coding scheme was developed so that extended written or illustrative responses provided by students could be allocated to one of a small number of mutually exclusive categories. The categories were devised using the combined evidence of previous research, trial data and an analysis of the range of responses received in the actual data collection. Appendix B contains the categories that were derived for all 'Pancakes' items. A team of raters (with science education backgrounds) was then used to read the students' work and code their responses according to these qualitative categories.

The full report of the study (Adams, Doig and Rosier, 1991) provides detailed information on the proportions of Year 5 and Year 9 students whose conceptions could be allocated to each of these qualitative categories. This detailed information provides a wealth of information about student conceptions that supports previous research studies and identifies new conceptions in a number of areas. We expect that this detailed information will be of considerable value in curriculum development. It does not however give an integrated picture of the status of students' science beliefs.

**FITTING A MEASUREMENT MODEL TO THE DATA**

Masters (1991) has recently shown how Rasch measurement principles (Rasch, 1960; Wright and Stone, 1980; Wright and Masters, 1982) can be coupled with qualitative data collection in order to construct descriptions of student learning in particular domains. He illustrates this point through the re-analysis of a set of data collected in the phenomenographic tradition by Renström, Andersson, and Marton (1990).

To apply these procedures with the TSSBs it was necessary to order the categories of response that were identified for each of the TSSB items and assign them integer level labels which indicated the ordering of the qualitative responses amongst the other responses to the same stimulus. The level indicators cannot be compared across items and in many cases two or more responses were assigned the same level. In Appendix B we have labelled the level of each of the alternatives. These categories have been ordered hierarchically and have been labelled accordingly.

To explore the value of applying measurement principles to the TSSBs the data was calibrated using the computer program Quest (Adams and Khoo, 1991) to fit the Rasch partial credit model (Masters, 1982). The results of the calibration for the 'Pancakes' TSSB is shown in Table 1.

Table 1 contains information for each of the items in this TSSB. The first column indicates the item number and label. The columns labelled thresholds are expressions of the item difficulty. These difficulties are expressed on an arbitrary interval scale that typically ranges from -3.0 to 3.0. The usefulness of these threshold estimates will become more apparent in the discussion of the variable map that are shown in Figure 3. Technical details on the calculation and interpretation of the thresholds are available in Masters (1988) and Adams and Khoo (1991). The value that accompanies each threshold estimate is an estimate of the standard error.

The last column expresses the fit of each of the items to the commonly defined underlying dimension. The fit test that we have reported is the weighted mean square statistic described by Wright and Masters (1982). It has an expected value of 1.0 when the items are compatible with the intention of a common underlying dimension. Fit tests for item response models like the partial credit model cause considerable difficulty and controversy within the psychometric community. Our practice is to use the weighted mean square statistic like an 'effect size' and consider values less than 1.2 as indications of acceptable misfit although it is always wise to pay some attention to the worst fitting items.

The results reported in Table 1 do not indicate any items that have failed our fit criteria. At some future date we expect to undertake more detailed fit analyses but these results encourages us to continue exploring the value of using this material to describe student science learning.

Table 1 Item Difficulties and Fit Statistics for The Structure of Matter

| ITEM NAME | THRESHOLDS 1 | 2 | 3 | 4 | FIT |
|---|---|---|---|---|---|
| 1 | 1.55 | | | | 1.02 |
| Flour | 0.10 | | | | |
| 2 | -1.95 | -0.72 | -0.61 | 1.17 | 1.19 |
| States | 0.16 | 0.12 | 0.12 | 0.14 | |
| 3 | 0.94 | 1.59 | | | 0.94 |
| Dissolving | 0.18 | 0.18 | | | |
| 4 | -0.55 | 0.79 | 1.30 | | 0.97 |
| Change of state | 0.12 | 0.14 | 0.17 | | |
| 5 | -0.78 | -0.07 | 0.41 | 1.38 | 1.16 |
| Condensation | 0.10 | 0.11 | 0.13 | 0.17 | |
| 6 | 0.00 | 1.97 | | | 1.01 |
| Conservation | 0.12 | 0.19 | | | |
| 7 | -1.29 | 0.06 | 1.24 | | 1.09 |
| Bubbles | 0.12 | 0.13 | 0.13 | | |
| 8 | -0.18 | 0.00 | 3.32 | | 1.12 |
| Cooking | 0.12 | 0.12 | 0.31 | | |
| 9 | -0.57 | 1.08 | | | 0.89 |
| Evaporation | 0.14 | 0.14 | | | |
| Sample Size = 975<br>Person Separation Reliability = 0.64<br>Mean Person Weighted Mean Square = 0.95 | | | | | |

**VARIABLE MAPS**

Figure 3 maps the variable that the we have constructed from the calibrated item difficulties. Each map has a vertical scale that represents increasing difficulty and in the middle panel the difficulty thresholds for the items are plotted. We use the notation 'x.y' to indicate the difficulty of achieving level y on item x. The left side of the figure indicates the distribution of student scores over the dimension—these maps rely on the fact that the model produces person ability estimates and item difficulty estimates that are expressed on a common scale.

Figure 3 Variable map for the structure of matter (Pancakes).

| | DISTRIBUTION OF STUDENTS | ITEMS | DESCRIPTION |
|---|---|---|---|
| | | 8.3 | |
| 3.0 | | | |
| | | | Students have a notion of chemical reactions |
| 2.0 | X | 6.2 | |
| | XX | | Students can describe simple processes such as evaporation, condensation, melting using the particulate model of matter. |
| | | 3.2 | |
| | | 1.1 | |
| | XXX | | |
| | | 4.3 | |
| | | 5.4 | |
| | X | 2.4 | |
| | | 7.3 | |
| | XXXX | 9.2 | |
| 1.0 | X | 3.1 | Students are aware that during processes such as dissolving, condensing and cooking, changes occur that are not easily observable. |
| | XXX | 4.2 | |
| | XXXXX | | |
| | XX | | |
| | XXXXXX | 5.3 | |
| | XXXXXXXX | | |
| | XXXXXXXXX | | |
| .0 | XXXXXXXXXXXXXX | 6.1 | |
| | XXX | 5.2 | |
| | | 8.2 | |
| | XXXXXXXXXXXXXXX | 8.1 | |
| | | | Students can identify key components but have little or no recognition of things or processes beyond the directly observable. |
| | XXXXXXXXXXXXXXXXXX | 2.3 | |
| | XXXXXXXXXXXXXXXXXXXXXX | 4.1 | |
| | XXXXX | 2.2 | |
| | XXXXXXXXXXXXXXXXXXX | 9.1 | |
| | XXXXXXXXXXXXXXXXX | 5.1 | Students' responses rely upon examples and 'magical' changes. |
| -1.0 | XX | | |
| | XXXXXXXXXXXXXX | | |
| | X | | |
| | XXXXXXXXX | 7.1 | |
| | | | Students' responses rely upon simple observations and definitions. |
| | X | | |
| | XXXXX | | |
| -2.0 | | 2.1 | |

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                                         |
                                         |
                                         |
                                      X  |
                                    XXX  |
                                         |
                                         |
 -3.0                                    |
  Each X represents 5 students
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If an item and a person are located at the same position on the scale then we have estimated that the person has a fifty percent chance of being able to successfully complete the item. The right most column is a content referenced description of the dimension that we have constructed. These descriptions are generalizations that are extracted from the task difficulties that lie in the region. These descriptions are not precisely 'bounded' which assists in underscoring that this is a probabilistic model, and that error of measurement must also be taken into consideration. The validity of this, and the other TSSB continua is secured against the fact that they appear to be consistent with research findings from more traditional constructivist studies.

**FURTHER DEVELOPMENTS**

The technique outlined above for one aspect of science has been extended to other curriculum areas where the researcher's desire was to explore the underlying concepts and beliefs held by the students.

Following the success of the 1990 Victorian Science Achievement Study (VSAS) the Minister for Education commissioned the ACER to survey social education learning in Victorian schools. This study (VSEAS) was undertaken in 1992. Although data has not been finally analyzed, preliminary results indicate that sensible and useful continua can be constructed for social education.

A smaller project using a short story as the stimulus material investigated beliefs of eight-year-olds about numbers and calculators. One half of the sample (N=200) were drawn from schools where a hand-held calculator is part of the mathematical life of the children from their first day at school, while the remaining children had only limited calculator access. Differences in both the type and use of numbers, the functioning of a calculator, and how calculators effect learning were surveyed and the results reported in a manner similar to that of the science study. A continuum describing the conceptual development of these aspects of mathematics was constructed, enabling discussion, curriculum planning, and diagnosis.

**CONCLUSIONS**

It is apparent from the close parallel between the results of this study and those of other researchers that the methodology described can be of benefit in exploring student conceptions and belief systems. This is an advance in methodology which should be of especial interest for those involved in large-scale surveys and curriculum development. The fact that little interest has been shown to date may stem either from naïvety or disinterest. Many involved in qualitative research eschew 'quantifying', but we believe that this is a mistaken belief that numbers are *per se* 'bad'. We believe that qualitative research need not necessarily be 'number' free, but that the data collection, interpretation and reporting springs from the underlying philosophical approach of the researcher. The approach of some qualitative research indeed may be as rigid as any quantitative method. This, we believe, is not useful. Openness to other alternatives should be a hallmark of good research practice.

It has been our intention to describe a methodology that allows as free a data collection as possible. While recognizing that one-to-one interviews, video taping and the like are probably the best form of data collection, it is not always possible to use these techniques. Our approach has been driven by need, and emulating interviews for a large scale seemed a possible solution. What we have demonstrated is that the results of such a research technique can be interpreted to give insights into conceptual understanding , which are both valid and reliable.

Two major features stand out; first that it has been possible to provide a continuum, rather than a collection of 'bits'. This reïnforces the constructivist view that conceptions are neither piece-meal nor necessarily hierarchical. The probabilistic nature of the data analysis takes into account the findings of other researchers that conceptions are context dependent, not fixed, and that conceptual development is not necessarily a smooth, ever 'increasing' process. What the analysis does provide, however, is an overview of conceptual development based on student data rather than only expert opinion, thus highlighting 'anomalies' or mismatches, between curriculum and student.

Second, this approach has demonstrated the possibility of describing student performance across disparate but related notions. This is evident in the 'Pancakes' TSSB where the focus on the structure of matter is described by items on various facets of the particulate model and its application to different events. Whereas more common approaches would leave these facets as separate entities, our analysis provides a single, integrated view of students' understanding of all these facets.

The last point to be made refers to the title of this paper. Is it naïvety or disinterest that prevents new techniques, such as the one described, from gaining acceptance and becoming part of the researcher's armory?

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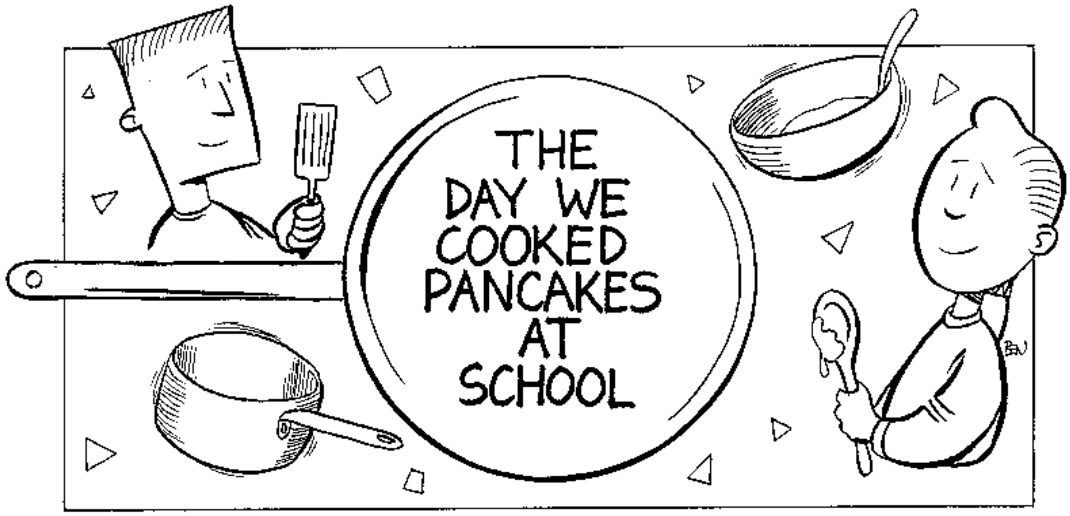
**APPENDIX A**

**THE DAY WE COOKED PANCAKES AT SCHOOL**

**(THE STRUCTURE OF MATTER TSSB)**



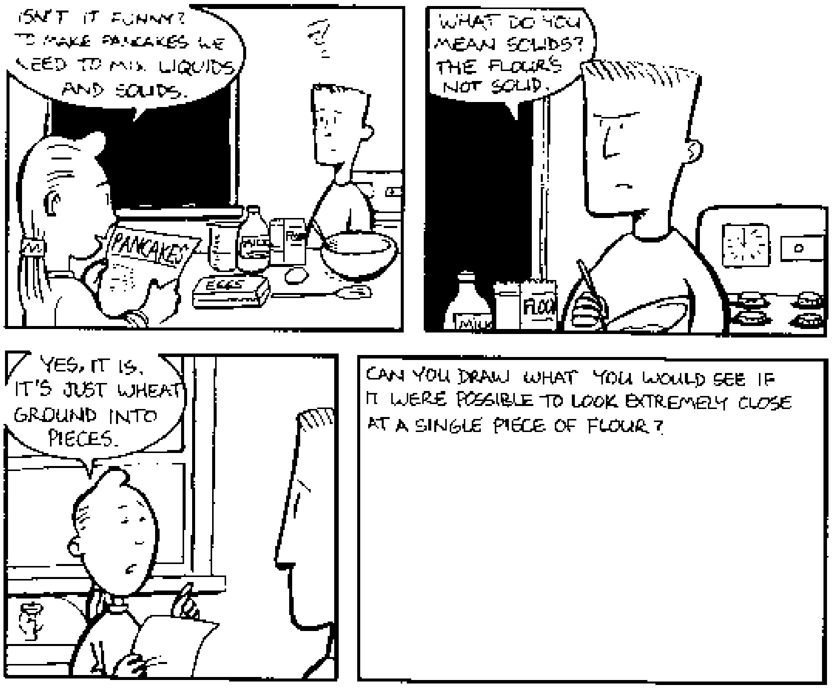

A UNIT FOR TAPPING STUDENTS' SCIENCE BELIEFS

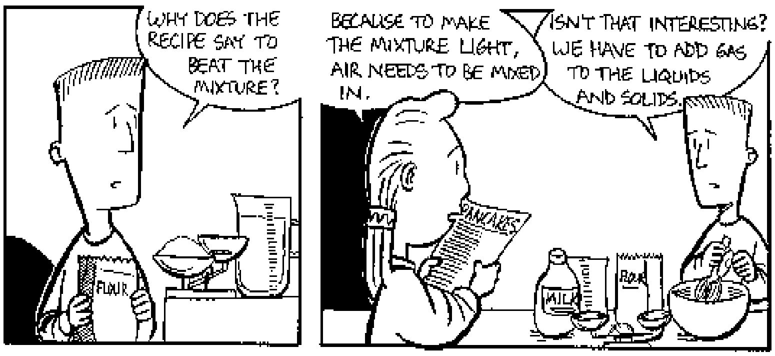
NAME: ____________________

GRADE: ____________________

SCHOOL: ____________________

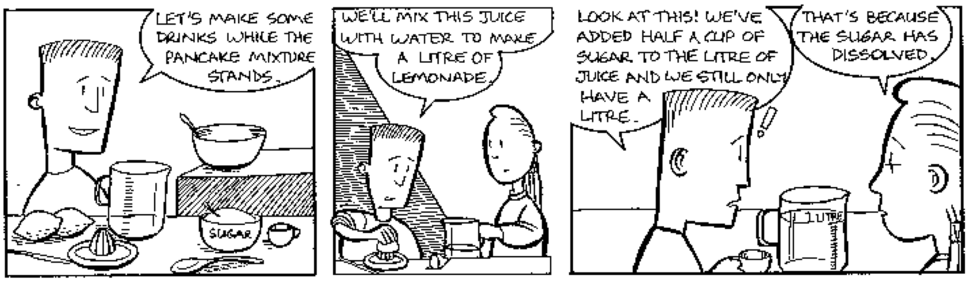
ACER


ISN'T IT FUNNY? TO MAKE PANCAKES WE NEED TO MIX LIQUIDS AND SOLIDS.
PANCAKES
EGGS
WHAT DO YOU MEAN SOLIDS? THE FLOUR'S NOT SOLID.
MILK
FLOUR
YES, IT IS. IT'S JUST WHEAT GROUND INTO PIECES.
CAN YOU DRAW WHAT YOU WOULD SEE IF IT WERE POSSIBLE TO LOOK EXTREMELY CLOSE AT A SINGLE PIECE OF FLOUR?




· CAN YOU DRAW A PICTURE THAT SHOWS HOW A SOLID, A LIQUID AND A GAS ARE DIFFERENT ?

| SOLID | LIQUID | GAS |
|---|---|---|
| | | |



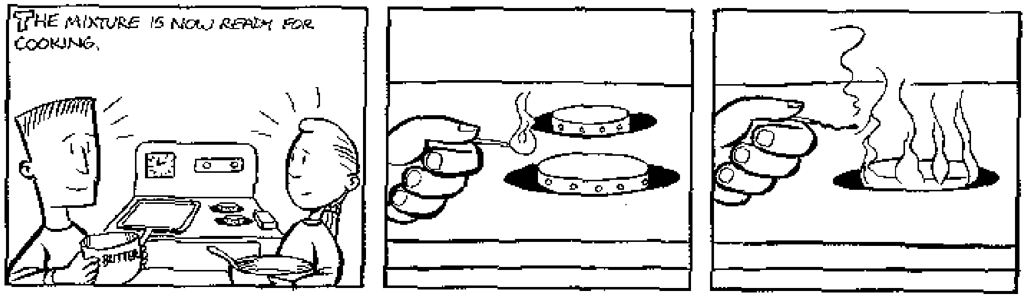

WHEN THINGS DISSOLVE, THE TOTAL VOLUME DOESN'T INCREASE. DRAW AND LABEL A PICTURE THAT EXPLAINS WHAT HAPPENS WHEN THINGS DISSOLVE.


HOW DOES HEAT MELT ICE INTO WATER?

________________________________________

________________________________________

DRAW A PICTURE THAT SHOWS HOW WATER AND ICE ARE DIFFERENT.




WHERE DOES THE WOOD GO WHEN THE MATCH BURNS?

______________________________

______________________________

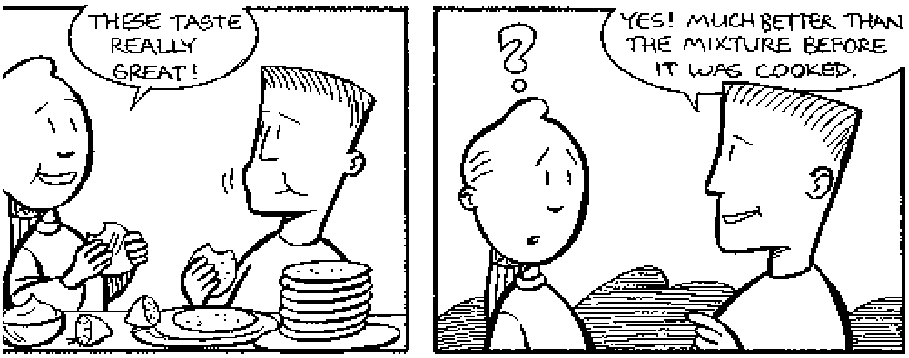
DOES A MATCH HAVE THE SAME WEIGHT BEFORE AND AFTER IT BURNS? EXPLAIN YOUR ANSWER.

______________________________

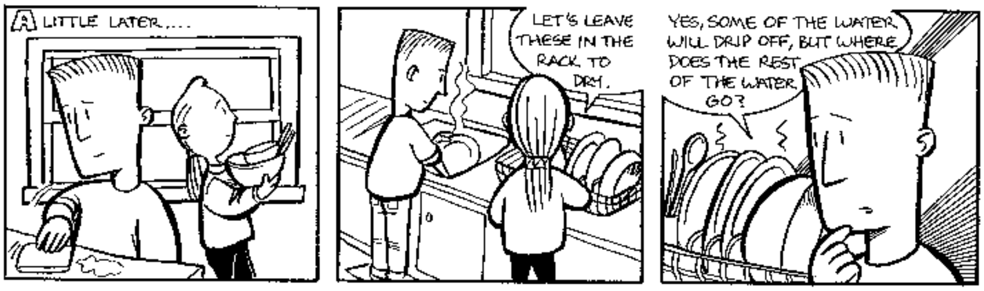
______________________________

______________________________


WHAT DO YOU THINK THE BUBBLES ARE MADE FROM?




WHAT HAS COOKING DONE TO THE MIXTURE?




WHAT DOES HAPPEN TO THE WATER THAT DOESN'T DRIP OFF?

______________________________

______________________________

______________________________

WHERE DOES THE WATER GO?

______________________________

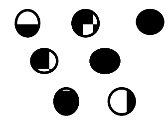
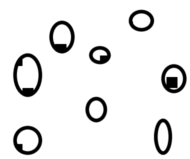
______________________________

## APPENDIX B

## RESPONSE CATEGORIES FOR THE STRUCTURE OF MATTER TSSB

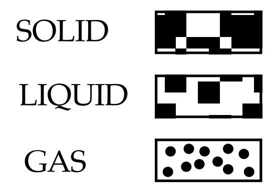
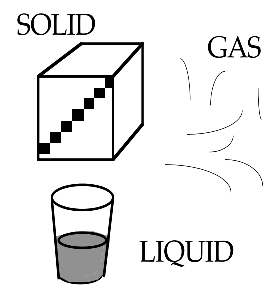
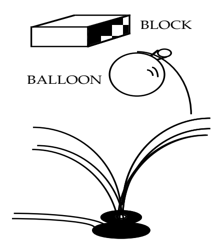
## Item 1 Structure of a solid

Purpose: To determine if students spontaneously acknowledge the existence of a finer structure in matter – a structure that cannot be observed with the naked eye.

| Score | Description | Examples |
|---|---|---|
| 1<br><br>Particulate | The response indicates that flour is made up of smaller particles. The particles may be cellular, molecular or atomic. |  |
| 0<br><br>Continuous | The 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’. |  |

## Item 2 States of matter

Purpose: To explore the way that students would choose to represent the distinction between different states of matter.

| Score | Description | Examples |
|---|---|---|
| 4<br>Particulate | The response indicates that solids, liquids and gases are made up of smaller particles. The state is determined by the arrangement of these particles. |  |
| 3<br>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<br>Properties | The response focuses 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<br>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 whether students can apply the particulate model to explain the process of dissolving.

| Score | Description | Examples |
|---|---|---|
| 2<br>Suspended particulate | The response use the particulate model to explain how the particles of sugar can become suspended in between the particles of the liquid. | |
| 1<br>Invisible | The response indicates that the grains of sugar become 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<br>Mixes in | The response simply states that the sugar mixes in. There is no explanation of the mixing process that blends the sugar and liquid. | |
| 0<br>Disappears | The 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 a substance changing from one state to another. In this case ice becoming water.

| Score Label | Description | Examples |
|---|---|---|
| 3<br><br>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 rearrange. | |
| 2<br><br>Particulate (incomplete) | The response indicates that water and ice are the same substance. The particulate model is used to illustrate the distinction but the role heat plays in the change is not explained. | |
| 1<br><br>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 affects 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 whether students can apply the particulate model to explain the process of condensation.

| Score Label | Description | Examples |
|---|---|---|
| 4<br><br>Scientific | The 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<br><br>Condensation | The 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.<br><br>From the atmosphere. |
| 2<br><br>Coldness | The 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 atmosphere. | From the ice.<br><br>The coldness makes it frost. |
| 1<br><br>From the jug | The response suggests that the water has come from inside the jug. | From the water inside the jug when the ice melts. |
| 0<br><br>Through the jug | The 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**

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 Label | Description | Examples |
|---|---|---|
| 2<br>Conservation | The response gives the products of burning as heat, gas, and ash with a supporting description of the weight of the products. | |
| 1<br>Ash and gas | The 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<br>Magic | The 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. These should be scored **0**.

## Item 7 What's in a bubble?

Purpose: To determine whether students regard heat as a substance.

| Score Label | Description | Examples |
|---|---|---|
| 3<br><br>Heat expanded gases | The response indicates that the bubbles are made from hot air and/or gases 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<br><br>Heat | The 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.<br><br>Air and heat. |
| 1<br><br>Unexplained gases | The response suggests that bubbles are made of air or gas but no mechanism is given. | Oxygen and air gases.<br><br>The air from inside the mixture when it was beaten up. |
| 0<br><br>Other substances | The response indicates that 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 Label | Description | Examples |
|---|---|---|
| 3<br><br>Chemical reaction | The 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<br>Mixes | The 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<br><br>Liquids removed | The response indicates that cooking dries out the mixture. The only change caused by cooking is the removal of liquids. | Dried it out.<br><br>Evaporated out all of the water. |
| 0<br><br>Changes taste | The 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.<br><br>When it gets hot it gets tastier. |

## Item 9 Evaporation

Purpose: To determine student awareness and understanding of evaporation.

| Score Label | Description | Examples |
|---|---|---|
| 2 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 give a complete explanation of the process. Some responses of this type suggest that evaporated water *turns into* air. | It evaporates into the atmosphere.<br><br>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.<br><br>In the dishes. |