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What Science Do Students Want to Learn ? What Do Students Know About Science?

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What science do students want to learn? What do students know *about* science?

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Barry McCrae joined ACER in 2001 as a Principal Research Fellow and leader of the Mathematics, Science and Technology test development team. Associate Professor McCrae was previously Deputy Head of the Department of Science and Mathematics Education at the University of Melbourne where he now holds an honorary appointment of Principal Fellow. At the University, Barry was involved with the pre-service and post-service training of mathematics and science teachers, both primary and secondary. During his career, Barry has made significant contributions at state and national levels in the fields of mathematics education and computer education.

At ACER Barry has undertaken key roles in a number of national and international projects, including directing state-wide assessments and producing the Australian report for the TIMSS 1999 Video Study of Year 8 mathematics teaching. Barry played a leading role in the PISA 2003 assessment of problem solving and managed framework and item development for the PISA 2006 assessment of scientific literacy. This included the conceptualisation and development of items for the optional computer-based assessment, and items to assess students' attitudes toward science. Barry is overall head of framework and item development for PISA 2009.

Abstract

In 2006, for the first time, science will be the major focus of the PISA assessment of 15-year-olds. A major innovation in PISA 2006 is that many of the science units contain one or two items designed to assess students' attitudes towards science – in particular, their interest in learning about science and their support for scientific enquiry. A second major innovation is that some of the items assess students' knowledge about science – that is, their knowledge of scientific methodology. This paper presents some field trial results that shed light on what science students want to learn, and how their knowledge about science compares with their knowledge of science (biology, chemistry, physics, Earth and space science).

PISA 2006 is the third cycle of the OECD Programme for International Student Assessment (PISA)[1] which is designed to measure how well 15-year-olds are prepared for life beyond school as they approach the end of compulsory schooling. PISA takes place every three years and covers the domains of reading, mathematical and scientific literacy. An ACER-led consortium has been responsible for the conduct of PISA since its inception in 2000. In 2006, for the first time, science will be the major focus of the assessment.

Reading literacy was the major assessment domain in PISA 2000 and mathematical literacy was the major focus in PISA 2003. PISA 2000 was conducted in 32 countries, including 28 OECD countries (OECD, 2001), and 41 countries participated in PISA 2003, including all 30 OECD countries (OECD, 2004).

A total of nearly half a million 15-year-olds representing 58 countries are being assessed in the main PISA 2006 study. A total of about 3000 students from three of the countries (Denmark, Iceland and Korea) are also undertaking a computer-based assessment of science. In Australia, over 350 schools, drawn from both the government and non-government sectors in all states and territories, have been selected to take part in PISA 2006. During July and August, a random sample of up to 50 students from each chosen school will undertake the assessment – about 18, 000 students overall.

PISA 2006 scientific literacy framework

In accordance with science's elevation to major domain status in 2006, the PISA science framework (OECD, in press[2]) has been significantly expanded over that used for the 2000 and 2003 assessments. The PISA 2006 Science Expert Group, chaired by Rodger Bybee, was responsible for the development of the framework.

PISA 2006 Definition of scientific literacy

For the purposes of PISA 2006, *scientific literacy* refers to an individual's:

- scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues;
- understanding of the characteristic features of science as a form of human knowledge and enquiry;
- awareness of how science and technology shape our material, intellectual, and cultural environments; and
- willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

[1]www.pisa.oecd.org

[2]The information in this paper about the framework is taken almost directly from the OECD publication.

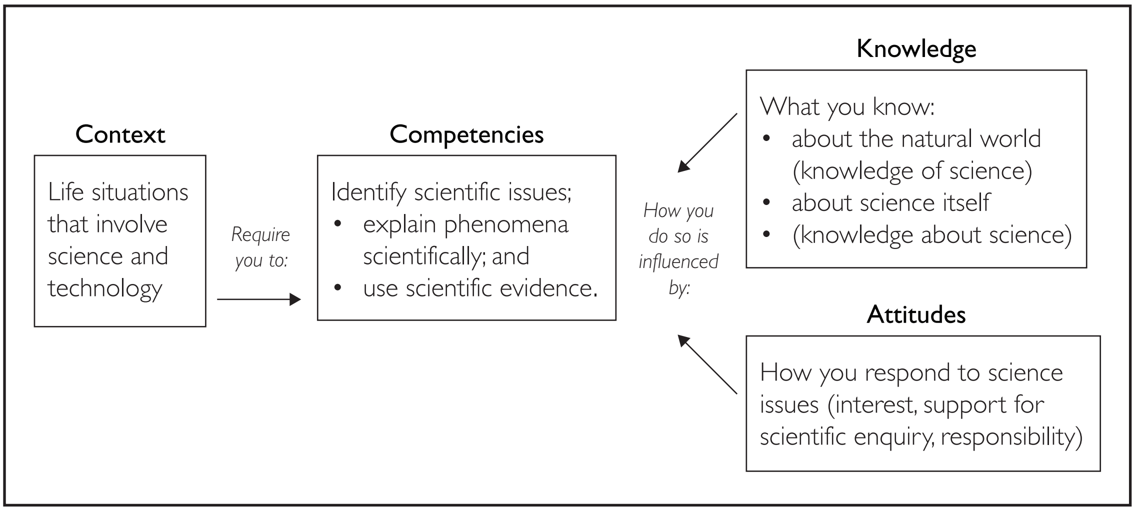

Figure 1 Framework for PISA 2006 science assessment

The previous PISA definition of scientific literacy has been enhanced to include aspects of individuals' attitudes towards science. The definition also gives more emphasis than before to an individual's understanding of the nature of science and to the role of science-based technology.

Organisation of the domain

For the purposes of assessment, the PISA 2006 definition of scientific literacy may be characterised as having the following four interrelated components as shown in Figure 1:

- Recognising life situations involving science and technology. This is the *context* for assessment.
- Understanding the natural world on the basis of scientific knowledge that includes both knowledge of the natural world, and knowledge about science itself. This is the *knowledge* component of the assessment.
- Demonstrating competencies that include identifying scientific issues, explaining phenomena scientifically, and using scientific evidence. This is the *competency* component.
- Indicating an interest in science, support for scientific enquiry, and motivation to act responsibly towards natural resources and environments. This is the *attitudinal* dimension of the assessment.

Knowledge component

PISA 2006 will assess students' knowledge *of* science, selected from the major fields of physics, chemistry, biology, and Earth and space science, *and* their knowledge *about* science. Knowledge *about* science refers to knowledge of the means ('scientific enquiry') and goals ('scientific explanations') of science. This is elaborated in Figure 2. Knowledge *about* science questions will constitute approximately 40 per cent of the cognitive assessment.

Scientific enquiry
- origin (e.g., curiosity, scientific questions)
- purpose (e.g., to produce evidence that helps answer scientific questions, current ideas/models/theories guide enquiries)
- experiments (e.g., different questions suggest different scientific investigations, design).
- data type (e.g., quantitative [measurements], qualitative [observations])
- measurement (e.g., inherent uncertainty, replicability, variation, accuracy/precision in equipment and procedures)
- characteristics of results (e.g., empirical, tentative, testable, falsifiable, self-correcting)

Scientific explanations
- types (e.g., hypothesis, theory, model, law)
- formation (e.g., data representation; role of extant knowledge and new evidence, creativity and imagination, logic)
- rules (e.g., must be logically consistent; based on evidence, historical and current knowledge)
- outcomes (e.g., produce new knowledge, new methods, new technologies; lead to new questions and investigations)

Figure 2 PISA 2006 knowledge *about* science categories

Attitudinal dimension

The PISA 2006 science assessment will evaluate students' attitudes in three areas: *Interest in science, Support for scientific enquiry*, and *Responsibility towards resources and environments* (see Figure 3). The student questionnaire will be used to gather data on students' attitudes in all three areas in a non-contextualised manner. Data concerning students' *Support for scientific enquiry*, and one aspect of their *Interest in science* (namely, their *Interest in learning about science*), also will be gathered by *embedding* Likert-style items in about two-thirds of the test units. The decision to assess students' attitudes towards science reflects the view expressed in the PISA science framework that they should be regarded as important *outcomes* of science education.

The 'scores' on the embedded attitudinal items will be used to construct scales for *Interest in learning about science* and *Support for scientific enquiry*. They will *not* be combined with the scores on the other test items to produce an overall score of scientific literacy.

PISA 2006 science test items

PISA science items are arranged in groups (units) based around a common stimulus. Two sample units, *Bread Dough* and *Health Risk?*, are included in the Appendix to this paper. The items shown were used in the field trial in 2005 as part of the item development process for the 2006 PISA main study but are *not* included in the final selection. Some of these items have undergone minor revision since the field trial and some of them have measurement properties that make them less than ideal for inclusion in an international test, but they are nevertheless useful for illustrative purposes.

Question 1, 3 and 4 of *Bread Dough* assess the competency 'Explaining phenomena scientifically', and draw on students' knowledge of physical systems (in particular, chemistry). Question 2 requires students to recognise which variables need to be changed and which need to be controlled in an experiment and so it assesses students' knowledge *about* science (category: Scientific enquiry). The competency classification is 'Identifying scientific issues'.

The final item in *Bread Dough* (Question 5) is the only released item that was designed to assess students' *Support for scientific enquiry*. Like all attitudinal items, it is placed last in the unit in order that students engage with the context prior to providing an opinion on the three statements.

Attitudinal items are distinctively formatted to remind students that they have no correct answer and will not count in their test score. Question 3 of *Health Risk?* is an example of an item designed to assess students' *Interest in learning about science*. The other two items in *Health Risk?* assess students' knowledge about scientific enquiry. Question 1 requires students to make a judgement about the relevance of a scientific study and Question 2 requires the identification of relevant variables that were not controlled in the study. The competency involved in both questions is 'Using scientific evidence'.

Field trial results

During 2005, about 260 science items (70 units) were trialled for inclusion in the PISA 2006 assessment. The field trial was conducted in all 58 countries participating in PISA 2006 and involved over 95 000 students. In this section, some results of the field trial are presented. Note, however, that convenience samples rather than random samples were employed in the field trial and so they cannot be regarded as representative samples of 15-year-old students. Accordingly, these results must be treated with caution and regarded as hypotheses to be investigated when analysing the main study results rather than as substantiated findings.

Students' attitudes towards science

Interest in learning about science: For the sample unit *Health Risk?*, above average interest was shown in the second and third statements of Question 3 but low interest was shown in the first statement. In general, students expressed most interest in learning about health or safety issues that they may encounter personally (e.g. 'Learning which diseases are transmitted in drinking water'), and least interest in learning about abstract scientific explanations (e.g. 'Learning about the different arrangements of atoms in wood, water and steel') and how scientific research is conducted.

This outcome is in agreement with that of Osborne and Collins (2001) who found that students are most interested in the aspects of science that they perceive as being relevant to their lives, and least interested in topics that they perceive as being of little relevance to themselves. Further support comes from the responses of students in England to the ROSE questionnaire[3]. Jenkins and Pell (2006) report that girls were most interested in learning about health-related issues, and that topics such as 'How crude oil is converted into other materials' held little interest for both boys and girls. However, the popularity of health-related issues was found to be not as strong for boys

[3]The Relevance of Science Education (ROSE) project is an international comparative study designed to gather and analyse information from 15-year-olds about their attitudes to science and technology and their motivation to learn about science and technology. See www.ils.uio.no/english/rose/

who expressed stronger interest in 'destructive technologies and events'.

Support for scientific enquiry: The 'personal relevance' influence was also the main factor here with most support being shown for investigation into health and safety issues (e.g. 'It is important to research how diseases are spread'), although a high level of support also was expressed for research that would assist the survival of endangered species. Least support was expressed for research that appeared to have little or no practical application (e.g. 'Studying fish in a tank is important even though the fish may behave differently in the wild').

Interestingly, students tended not to value scientists' explanations of everyday phenomena more than alternative explanations. For example, for *Bread Dough*, below average support was shown for the second and third statements and low support for the third statement.

Students' scientific knowledge

The field trial showed the six cognitive sample items included with this paper to be of moderate to high difficulty. The hardest items in the group were two of the three knowledge *about* science items, Question 2 of *Bread Dough* and Question 2 of *Health Risk?*. The easiest item, answered correctly by over 40 per cent of students, was Question 4 of *Bread Dough* which assesses understanding of the particle model of matter.

Internationally, no gender difference was apparent in the performance on the sample items or on the test overall. However, as shown in Figure 4, gender differences become apparent when performance is analysed according to the knowledge component of the items: physical systems (PS), Earth and space systems (ES), living systems (LS), and knowledge *about* science.

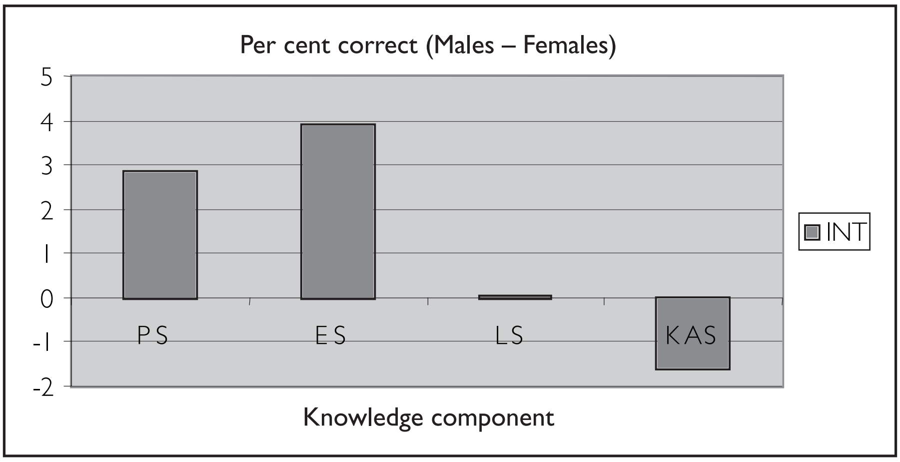

Figure 4 PISA 2006 field trial items per cent correct according to knowledge component

The gender difference pattern for the knowledge of science items is consistent with that found for Year 8 students in TIMSS 2002/03 (Martin, Mullis, Gonzalez, & Chrostowski, 2004). Of most interest, though, since this appears to be the first international assessment of students' knowledge *about* science, is that females out-performed males on these items.

Summary

Science is the major assessment domain for the first time in PISA 2006. The definition of scientific literacy has been expanded to include aspects of individuals' attitudes towards science and a much stronger emphasis than before is placed on individuals' understanding of the nature and methodology of science itself (their knowledge *about* science). An innovative aspect of the 2006 assessment is that items designed to assess students' 'interest in learning about science', and their 'support for scientific enquiry', are embedded in the test units.

The field trial conducted during 2005 in all 58 countries participating in PISA 2006 yielded some interesting preliminary results concerning students' attitudes and knowledge. Of particular interest is that girls outperformed boys on knowledge *about* science items. This and other field trial findings will be the subject of closer scrutiny when the main study results become available throughout the second half of 2006.

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Appendix: PISA 2006 Sample Science Items

BREAD DOUGH

To make bread dough, a cook mixes flour, water, salt and yeast. After mixing, the dough is placed in a container for several hours to allow the process of fermentation to take place. During fermentation, a chemical change occurs in the dough: the yeast (a single-celled fungus) helps to transform the starch and sugars in the flour into carbon dioxide and alcohol.

Question 1: BREAD DOUGH

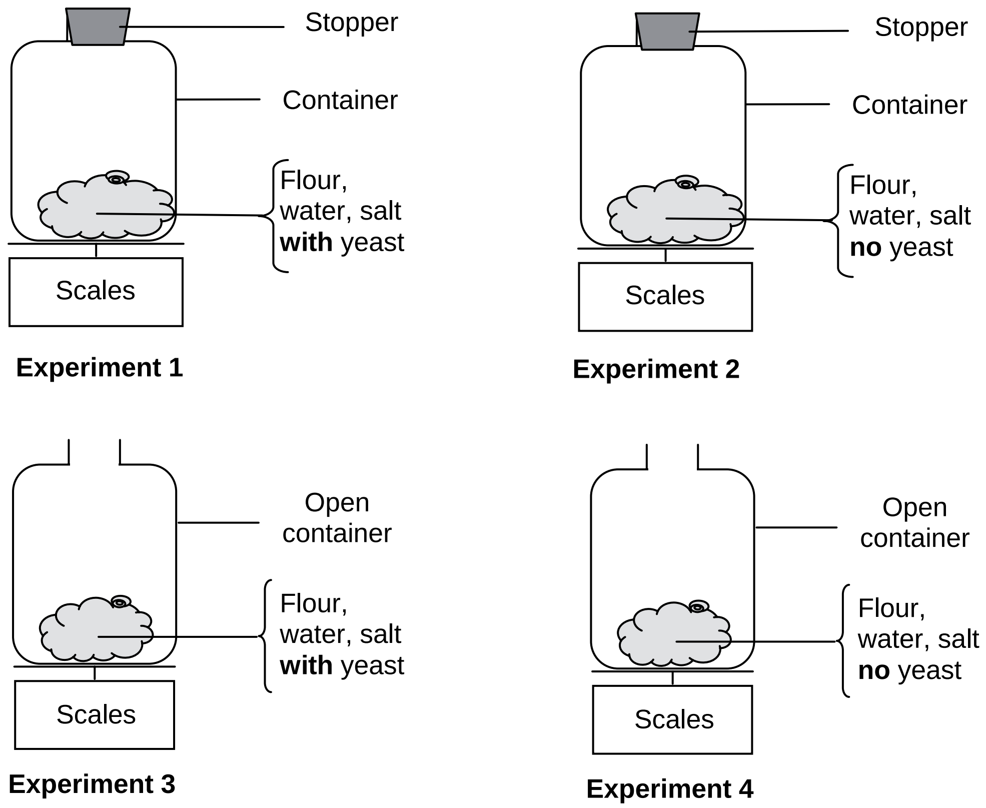
Fermentation causes the dough to rise. Why does the dough rise?

A The dough rises because alcohol is produced and turns into a gas.
B The dough rises because of single-celled fungi reproducing in it.
C The dough rises because a gas, carbon dioxide, is produced.
D The dough rises because fermentation turns water into a vapour.

Question 2: BREAD DOUGH

A few hours after mixing the dough, the cook weighs the dough and observes that its weight has decreased.

The weight of the dough is the same at the start of each of the four experiments shown below. Which **two** experiments should the cook compare to test if the **yeast** is the cause of the loss of weight?



A The cook should compare experiments 1 and 2.
B The cook should compare experiments 1 and 3.
C The cook should compare experiments 2 and 4.
D The cook should compare experiments 3 and 4.

Question 3: BREAD DOUGH

In the dough, yeast helps to transform starch and sugars in the flour. A chemical reaction occurs during which carbon dioxide and alcohol form.

Where do the **carbon atoms** that are present in carbon dioxide and alcohol come from? Circle 'Yes' or 'No' for each of the following possible explanations.

Is this a correct explanation of where the carbon atoms come from?	Yes or No?
Some carbon atoms come from the sugars.	Yes / No
Some carbon atoms are part of the salt molecules.	Yes / No
Some carbon atoms come from the water.	Yes / No

Question 4: BREAD DOUGH

When the risen (leavened) dough is placed in the oven to bake, pockets of gas and vapours in the dough expand.

Why do the gas and vapours expand when heated?

A Their molecules get bigger.
B Their molecules move faster.
C Their molecules increase in number.
D Their molecules collide less frequently.

Question 5: BREAD DOUGH

How much do you agree with the following statements?

Tick only one box in each row.

		Strongly Agree	*Agree*	*Disagree*	*Strongly Disagree*
a)	I would trust a scientific report more than a baker's explanation of the weight loss in dough.	☐1	☐2	☐3	☐4
b)	Chemical analysis is the best way to identify the products of fermentation.	☐1	☐2	☐3	☐4
c)	Research into the changes that occur when food is prepared is important.	☐1	☐2	☐3	☐4

HEALTH RISK?

Imagine that you live near a large chemical factory that produces fertilisers for use in agriculture. In recent years there have been several cases of people in the area suffering from long-term breathing problems. Many local people believe that these symptoms are caused by the emission of toxic fumes from the nearby chemical fertiliser factory.

A public meeting was held to discuss the potential dangers of the chemical factory to the health of local residents. Scientists made the following statements at the meeting.

Statement by scientists working for the chemical company

‘We have made a study of the toxicity of soil in the local area. We have found no evidence of toxic chemicals in the samples we have taken.’

Statement by scientists working for concerned citizens in the local community

‘We have looked at the number of cases of long-term breathing problems in the local area and compared this with the number of cases in an area far away from the chemical factory. There are more incidents in the area close to the chemical factory.’

Question 1: HEALTH RISK?

The owner of the chemical factory used the statement of the scientists working for the company to argue that ‘the emission fumes from the factory are not a health risk to local residents’.

Give one reason, other than the statement by scientists working for the concerned citizens, for **doubting** that the statement by scientists working for the company supports the owner’s argument.

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Question 2: HEALTH RISK?

The scientists working for the concerned citizens compared the number of people with long-term breathing problems close to the chemical factory with those in an area far away from the factory.

Describe one possible difference in the two areas that would make you think that the comparison was not a valid one.

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Question 3: HEALTH RISK?

How much interest do you have in the following information?

Tick only one box in each row.

		High Interest	*Medium Interest*	*Low Interest*	*No Interest*
a)	Knowing more about the chemical composition of agricultural fertilisers	☐1	☐2	☐3	☐4
b)	Understanding what happens to toxic fumes emitted into the atmosphere	☐1	☐2	☐3	☐4
c)	Learning about respiratory diseases that can be caused by chemical emissions	☐1	☐2	☐3	☐4