Scientific Literacy

An important life skill for young people is the capacity to draw appropriate and guarded conclusions from evidence and information given to them, to criticise claims made by others on the basis of the evidence put forward, and to distinguish opinion from evidence-based statements. Science has a particular part to play here since it is concerned with rationality in testing ideas and theories against evidence from the world around. This is not to say that science excludes creativity and imagination, which have always played a central part in advancing human understanding of the world. Ideas which sometimes appear to have "come out of the blue" have been seized upon by a mechanism which Einstein described as "the way of intuition, which is helped by a feeling for the order lying behind the appearance" (Einstein, 1933). Which ideas are "seized upon" has depended historically upon their social acceptability at that time, so that developments in scientific knowledge depend not only on the creativity of individuals but also on the culture in which they are proposed. But once the creative leap is made and a new theoretical framework for understanding has been articulated, then it has to be followed by painstaking testing against reality. As Hawking (1988) has written:

> *"A theory is a good theory if it satisfies two requirements: it must accurately describe a large class of observations on the basis of a model that contains only a few arbitrary elements, and it must make definite predictions about the results of future observations"* (Hawking ,1988, p. 9).

Theories that do not meet these requirements, or cannot be tested, are not scientific theories. It is important for an educated citizen to be able to distinguish between the kinds of questions that can be answered by science and those which cannot, and between what is scientific and what is pseudo-scientific.

DEFINITION OF THE DOMAIN

Current thinking about the desired outcomes of science education for all citizens emphasises the development of a general understanding of important concepts and explanatory frameworks of science, of the methods by which science derives evidence to support claims for its knowledge, and of the strengths and limitations of science in the real world. It values the ability to apply this understanding to real situations involving science in which claims need to be assessed and decisions made. For example, Millar and Osborne (1998) have identified the focus of a modern science curriculum as being: "the ability to read and assimilate scientific and technical information and assess its significance". Their report continues:

> *"In this approach, the emphasis is not on how to 'do science'. It is not on how to create scientific knowledge, or to recall it briefly for a terminal examination. …Thus, in science, students should be asked to demonstrate a capacity to evaluate evidence, to distinguish theories from observations and to assess the level of certainty ascribed to the claims advanced"* (Millar & Osborne, 1998).

These should be the products of science education for all students. For some students, the minority who will become the scientists of tomorrow, this will be extended to in-depth study of scientific ideas and to the development of the ability to "do science".

With these points in mind, it is considered that the essential goal of science education, which should be the focus of OECD/PISA, is that students should be scientifically literate. This term has been used in different contexts. For example, the International Forum on Scientific and Technological Literacy for All (UNESCO, 1993) offered a variety of views, such as:

> *"The capability to function with understanding and confidence, and at appropriate levels, in ways that bring about empowerment in the made world and in the world of scientific and technological ideas"* (UNESCO, 1993).

Included in the many different views of scientific literacy (reviewed by Shamos, 1995; Laugksch, 2000; see also Graeber & Bolte, 1997) are notions of levels of scientific literacy. For example, Bybee (1997) has proposed four levels, of which the lowest two are "nominal scientific literacy", consisting of knowledge of names and terms, and "functional literacy", which applies to those who can use scientific vocabulary in limited contexts. These are seen as being at levels too low to be aims within the OECD/PISA framework. The highest level identified by Bybee, "multidimensional scientific literacy", includes understanding of the nature of science and of its history and role in culture, at a level most appropriate for a scientific elite rather than for all citizens. It is, perhaps, the assumption that scientific literacy involves thinking at this level of specialisation that causes difficulty in communicating a more attainable notion of it. What is more appropriate for the purposes of the OECD/PISA science framework is closer to Bybee's third level, "conceptual and procedural scientific literacy".

Having considered a number of existing descriptions, OECD/PISA defines scientific literacy as follows:

> *Scientific literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity.*

The following remarks further explain the meaning condensed in this statement.

Scientific literacy…

It is important to emphasise not only that both scientific knowledge (in the sense of knowledge about science) and the processes by which this knowledge is developed are essential for scientific literacy, but that they are bound together in this understanding of the term. As discussed in more detail below, the processes are only scientific when they are used in relation to the subject matter of science. Thus, using scientific processes necessarily involves some understanding of the scientific subject matter. The view of scientific literacy adopted here

acknowledges this combination of ways of thinking about, and understanding, the scientific aspects of the world.

...use scientific knowledge to identify questions and to draw evidence-based conclusions...

In the above definition, scientific knowledge is used to mean far more than knowledge of facts, names and terms. It includes understanding of fundamental scientific concepts, the limitations of scientific knowledge and the nature of science as a human activity. The questions to be identified are those that can be answered by scientific enquiry, implying knowledge about science as well as about the scientific aspects of specific topics. Drawing evidence-based conclusions means knowing and applying processes of selecting and evaluating information and data, whilst recognising that there is often not sufficient information to draw definite conclusions, thus making it necessary to speculate, cautiously and consciously, about the information that is available.

...understand and help make decisions...

This phrase indicates first, that an understanding of the natural world is valued as a goal in itself as well as being necessary for decision-making and, second, that scientific understanding can contribute to, but rarely determines, decision making. Practical decisions are always set in situations having social, political or economic dimensions, and scientific knowledge is used in the context of human values related to these dimensions. Where there is agreement about the values in a situation, the use of scientific evidence can be non-controversial. Where values differ, the selection and use of scientific evidence in decision making will be more controversial.

...the natural world and the changes made to it through human activity...

The phrase *the natural world* is used as shorthand for the physical setting, living things and the relationships among them. Decisions about the natural world include those associated with science related to self and family, community and global issues. Changes made through human activity refer to planned and unplanned adaptations of the natural world for human purposes (simple and complex technologies) and their consequences.

It is relevant to note here, and will be made more explicit later, that scientific literacy is not a dichotomy. That is, it is not suggested that people can be categorised as being either scientifically literate or scientifically illiterate. Rather, there is a progression from less developed to more developed scientific literacy. For example, the student with less developed scientific literacy might be able to recall simple scientific factual knowledge (*e.g.,* names, facts, terminology, simple rules) and to use common science knowledge in drawing or evaluating conclusions. A more developed scientific literacy will show in being able to create or use simple conceptual models to make predictions or give explanations, to make and communicate them with precision, to analyse scientific investigations in relation to experimental design, to use data as evidence to evaluate alternative viewpoints or different perspectives and their implications, and to communicate evaluations with precision.

ORGANISATION OF THE DOMAIN

The OECD/PISA definition of scientific literacy comprises three aspects:

- *Scientific knowledge or concepts,* which will be assessed by application to specific subject matter;
- *Scientific processes* which, because they are scientific, will involve knowledge of science, although in the assessment this knowledge must not form the major barrier to success;
- *Situations or context* in which the knowledge and processes are assessed and which take the form of science-based issues.

Although these aspects of scientific literacy are discussed separately, it must be recognised that, in the assessment of scientific literacy, there will always be a combination of all three.

The first two of these aspects are used both for the construction of test items and for the characterisation of student performance. The third aspect ensures that in the development of the assessment items, due attention is paid to situating the science in a diverse range of relevant settings.

The following sections elaborate the three organising aspects. In laying out these aspects, the OECD/PISA framework has ensured that the focus of the assessment is upon the outcome of science education as a whole.

Scientific knowledge or concepts

Only a sample of scientific ideas can be assessed. Moreover, the purpose of OECD/PISA is not to report on all the knowledge that students may have, but to describe the extent to which they can apply their knowledge in contexts of relevance to their present and future lives. No attempt is made to identify a full list of knowledge that might be included, but rather to specify the criteria for selection. Thus the knowledge that is assessed is selected from the major fields of physics, chemistry, biological science and Earth and space science according to the following three criteria.

- The first of these is relevance to everyday situations. Scientific knowledge differs in the degree to which it is useful in every-day life. For example, although the theory of relativity gives a more accurate description of the relationships between length, mass, time and velocity, Newton's laws are more helpful in matters relating to the understanding of forces and motion encountered every day.
- The second criterion is that the knowledge and areas of application selected should have enduring relevance to life throughout the next decade and

beyond. Given that the major assessment of science is planned to take place in the year 2006, this cycle of OECD/PISA will focus on the knowledge likely to remain important in science and public policy for a number of years.

- The third criterion is that the knowledge required can be combined with selected scientific processes. This would not be the case where only recall of a label or of a definition was involved.

Figure 3.1 shows the outcome of applying these criteria to the content of the major fields of science. It lists major scientific themes, with a few examples of the knowledge relating to them. This knowledge is required for understanding the natural world and for making sense of new experience. It depends upon and derives from study of specific phenomena and events but goes beyond the detailed knowledge that comes from study of these things. The examples listed in Figure 3.1 are given to convey the meanings of the themes; there is no attempt to list comprehensively all the knowledge that could be related to each theme.

Figure 3.1 ■ **Major scientific themes for the assessment of scientific literacy**

- Structure and properties of matter (thermal and electrical conductivity)
- Atmospheric change (radiation, transmission, pressure)
- Chemical and physical changes (state of matter, rates of reaction, decomposition)
- Energy transformations (energy conservation, energy degradation, photosynthesis)
- Forces and movement (balanced/unbalanced forces, velocity, acceleration, momentum)
- Form and function (cell, skeleton, adaptation)
- Human biology (health, hygiene, nutrition)
- Physiological change (hormones, electrolysis, neurons)
- Biodiversity (species, gene pool, evolution)
- Genetic control (dominance, inheritance)
- Ecosystems (food chains, sustainability)
- The Earth and its place in the universe (solar system, diurnal and seasonal changes)
- Geographical change (continental drift, weathering)

Scientific processes

Processes are mental (and sometimes physical) actions used in conceiving, obtaining, interpreting and using evidence or data to gain knowledge or understanding. Processes have to be used in relation to some subject matter; there is no meaning to a content-free process. They can be used in relation to a wide range of subject matter; they become scientific processes when the subject matter is drawn from scientific aspects of the world and the outcome of using them is to further scientific understanding.

What are commonly described as the processes of science range widely over the skills and understanding needed to collect and interpret evidence from the world around us and to draw conclusions from it. The processes related to collecting evidence include those concerned with investigation in practice – planning and setting up experimental situations, taking measurements and making observations using appropriate instruments, etc. The development of these processes is included in the aims of school science education so that students can experience and understand how scientific understanding is built up and, ideally, the nature of scientific enquiry and scientific knowledge. Few will require these practical skills in life after school, but they will need the understanding of processes and concepts developed through practical, hands-on enquiry. Moreover, it has been strongly argued that what is traditionally regarded as the "scientific process", by which conclusions are drawn inductively from observations, and which is still reflected in much school science, is contrary to how scientific knowledge is developed (*e.g.*, Ziman, 1980).

Scientific literacy, as identified here, gives higher priority to using scientific knowledge to "draw evidence-based conclusions" than to the ability to collect evidence for oneself. The ability to relate evidence or data to claims and conclusions is seen as central to what all citizens need in order to make judgements about the aspects of their lives that are influenced by science. It follows that every citizen needs to know when scientific knowledge is relevant, distinguishing between questions which science can and cannot answer. Every citizen needs to be able to judge when evidence is valid, both in terms of its relevance and how it has been collected. Most important of all, however, every citizen needs to be able to relate evidence to conclusions based on it and to be able to weigh the evidence for and against particular courses of action that affect life at a personal, social or global level.

The distinctions that have just been made can be summarised briefly as giving priority to processes *about* science as compared with processes *within* science. It is important that the process skills listed in Figure 3.2 be read as being primarily about science and not primarily as they apply within science. All of the processes listed in Figure 3.2 involve scientific knowledge. In the first process the scientific knowledge is the essential factor. In the second and third processes this knowledge is necessary but not sufficient, since knowledge about collecting and using scientific evidence and data is essential.

Figure 3.2 ■ **The PISA 2003 scientific processes**

Scientific Literacy

- Process 1: Describing, explaining and predicting scientific phenomena
- Process 2: Understanding scientific investigation
- Process 3: Interpreting scientific evidence and conclusions

Some elaboration of these processes follows.

Describing, explaining and predicting scientific phenomena

In this process students demonstrate their understanding by applying appropriate scientific knowledge in a given situation. It includes describing or explaining phenomena and predicting changes, and may involve recognising or identifying appropriate descriptions, explanations and predictions.

Understanding scientific investigation

Understanding scientific investigation involves recognising and communicating questions that can be investigated scientifically and knowing what is involved in such investigations. It includes recognising scientifically investigable questions or suggesting a question that could be investigated scientifically in a given situation. It also includes identifying or recognising evidence needed in a scientific investigation: for example, what things should be compared, what variables should be changed or controlled, what additional information is needed, or what action should be taken so that relevant data can be collected.

Interpreting scientific evidence and conclusions

This means making sense of scientific findings as evidence for claims or conclusions. It may involve accessing scientific information and producing and communicating conclusions based on scientific evidence. It may also involve selecting from and communicating about alternative conclusions in relation to the evidence; giving reasons for or against a given conclusion in terms of the data provided, or identifying the assumptions made in reaching a conclusion; and reflecting on and communicating the societal implications of scientific conclusions.

Some scientific knowledge is needed for all three processes. In the case of the second and third, however, the knowledge is not intended to be the main "hurdle", since the aim is to assess the mental processes involved in gathering, evaluating and communicating valid scientific evidence. In the first process, on the other hand, it is the understanding of the scientific ideas involved that is being assessed and this understanding is the main hurdle.

It is important to point out that, for each of the processes listed above, there is a wide range of item difficulty, depending upon the scientific knowledge and areas of application involved. The OECD/PISA assessments ensure that, through country feedback and the field trial, the items selected for the main study are at the appropriate level of difficulty for 15-year-olds.

Situations or context: the areas of application

As indicated earlier, OECD/PISA includes important scientific knowledge relevant to the science curricula of participating countries without being constrained by the common denominator of national curricula. In accordance with its focus on scientific literacy, it does this by requiring application of selected scientific knowledge and the use of scientific processes in important situations reflecting the real world and involving ideas of science.

Figure 3.3 lists those areas of application of science that raise issues that the citizens of today and tomorrow need to understand and to make decisions about. It is these applications that guide the selection of content for units and the items within them. Figure 3.3 indicates the areas of application in which the scientific knowledge and processes will be assessed.

Figure 3.3 ■ **Areas of application for the science assessment**

- Science in life and health
  - Health, disease and nutrition
  - Maintenance of and sustainable use of species
  - Interdependence of physical/biological systems
- Science in Earth and environment
  - Pollution
  - Production and loss of soil
  - Weather and climate
- Science in technology
  - Biotechnology
  - Use of materials and waste disposal
  - Use of energy
  - Transportation

In framing test questions, it is necessary to consider not only the area of application, but also the setting in which the issue to be considered will be presented. In selecting the settings, it is important to keep in mind that the purpose of the assessment is to assess the ability of students to apply the skills and knowledge they have acquired by the end of the compulsory years of schooling. OECD/PISA requires that the assessment items should be framed in situations of life in general and not limited to life in school. In the school setting, scientific processes and knowledge may be confined to the laboratory or classroom, but increasingly an attempt is being made also in countries' science curricula to apply these to the world outside the school.

Real-world situations involve problems that can affect us as individuals (*e.g.*, food and energy use) or as members of a local community (*e.g.*, treatment of the water supply or siting of a power station) or as world citizens (*e.g.*, global warming, diminution of biodiversity). All of these are represented in the range of assessment items used in OECD/PISA. A further type of setting, appropriate to some topics, is the historical one, in which understanding of the advances in scientific knowledge can be assessed. In the framework of OECD/PISA the focus of the items is on matters relating to the self and family (personal), to the community (public), to life across the world (global), and on those that illustrate how scientific knowledge evolves and affects social decisions associated with science (historical relevance).

In an international study it is important that the areas of application used for assessment items should be chosen in the light of relevance to students' interests and lives in all countries. They should also be appropriate for assessing scientific processes and knowledge. Sensitivity to cultural differences has a high priority in item development and selection, not only for the sake of the validity of the assessment, but to respect the different values and traditions in participating countries. The areas of application chosen for the survey items are relevant and appropriate across the different countries, whilst involving the combination of scientific knowledge with the use of scientific processes.

By choosing these areas of application and settings, OECD/PISA is seeking to assess the application of knowledge most likely to have been gained in the science curriculum (although some may be gained from other subjects and from non-school sources). However, although the knowledge required is curricular knowledge, in order to find out if this has gone beyond learning isolated facts and is serving the development of scientific literacy, OECD/PISA is assessing the application of that knowledge in items reflecting real-life situations. Some of the examples of items presented below help to convey this point.

TEST CHARACTERISTICS AND EXAMPLES

In accordance with the OECD/PISA definition of scientific literacy, each assessment question (item) will require the use of one of the processes in Figure 3.2 and, as has also been noted, some scientific knowledge. As the examples below illustrate, what is identified as a defined test unit will take the form of several items linked to some initial stimulus material. Although each item in a unit has been identified as mainly assessing one of the scientific processes listed in Figure 3.2, some items may also assess other scientific processes, and draw on various aspects of scientific knowledge.

One reason for this structure is to make the units as realistic as possible and to reflect in them to some extent the complexity of real-life situations. Another reason relates to the efficient use of testing time, cutting down on the time required for a student to "get into" the subject matter of the unit by having fewer situations, about which several questions can be posed, rather than separate questions about a larger number of different situations. The necessity to make each scored point independent of others within the unit is recognised and taken into account. It is also recognised that it is all the more important to minimise bias that may be due to the choice of situation when fewer situations are used.

Examples of the items for assessing some of these processes will help to convey their operational meaning.

Science Unit 1

STOP THAT GERM!

Process 2 is assessed in two questions within this unit. The students are asked to read a short text about the history of immunisation:

> As early as the 11th century, Chinese doctors were manipulating the immune system. By blowing pulverised scabs from a smallpox victim into their patients' nostrils, they could often induce a mild case of the disease that prevented a more severe onslaught later on. In the 1700s, people rubbed their skins with dried scabs to protect themselves from the disease. These primitive practices were introduced into England and the American colonies. In 1771 and 1772, during a smallpox epidemic, a Boston doctor named Zabdiel Boylston tested an idea that he had. He scratched the skin on his six-year-old son and 285 other people and rubbed pus from smallpox scabs into the wounds. All but six of his patients survived.

Science Example 1.1

What idea might Zabdiel Boylston have been testing?

Scoring and comments on Science Example 1.1

Full Credit

Code 2: Answers with reference both to:

- the idea that infecting someone with smallpox will provide some immunity;

AND

- the idea that by breaking the skin, the smallpox was introduced into the blood stream.

Partial Credit

Code 1: Answers which refer to either of the above points.

No Credit

Code 0: Other responses.

Item type: *Open constructed-response*
Process: *Understanding scientific investigation (Process 2)*
Concept: *Human biology*
Situation: *Science in life and health*

Science Example 1.2

Give two other pieces of information that you would need to decide how successful Boylston's approach was.

Scoring and comments on Science Example 1.2

Full Credit

Code 2: Answers that provide the following TWO pieces of information:

- the rate of survival without Boylston's treatment;

AND

- whether his patients were exposed to smallpox apart from the treatment.

Partial Credit

Code 1: Answers that provide either of the above points.

No Credit

Code 0: Other answers.

Item type: *Open constructed-response*
Process: *Understanding scientific investigation (Process 2)*
Concept: *Human biology*
Situation: *Science in life and health*

Science Unit 2

PETER CAIRNEY

The following four items are part of a unit for which the stimulus material is a passage about Peter Cairney, who works for the Australian Road Research Board. The stimulus material is presented below.

> …Another way that Peter gathers information to improve road safety is by the use of a TV camera on a 13 metre pole to film the traffic on a narrow road. The pictures tell the researchers such things as how fast the traffic is going, how far apart the cars travel, and what part of the road the traffic uses. Then after a time, lane lines are painted on the road. The researchers can then use the TV camera to see whether the traffic is now different. Does the traffic now go faster or slower? Are the cars close together or further apart than before? Do the motorists drive closer to the edge of the road or closer to the centre now that the lines are there? When Peter knows these things he can give advice about whether or not to paint lines on narrow roads.

Science Example 2.1

If Peter wants to be sure that he is giving good advice, he might collect some other information as well beyond filming the narrow road. Which of these things would help him to be more sure about his advice concerning the effect of painting lines on narrow roads?

A. Doing the same on other narrow roads — Yes / No

B. Doing the same on wide roads — Yes / No

C. Checking the number of accidents in a certain time period before and after painting the lines — Yes / No

D. Checking the number of cars using the road before and after painting the lines — Yes / No

Scoring and comments on Science Example 2.1

Full Credit

Code 2: Answers that specify Yes, No, Yes, No, in that order.

Partial Credit

Code 1: Answers that specify Yes, No, No, No, in that order.

No Credit

Code 0: Any other combination of answers.

Item type: *Complex multiple-choice*
Process: *Understanding scientific investigation (Process 2)*
Concept: *Forces and movement*
Situation: *Science in technology*

Science Example 2.2

Suppose that on one stretch of narrow road Peter finds that after the lane lines are painted the traffic changes as below.

Speed	Traffic moves more quickly
Position	Traffic keeps nearer edges of road
Distance apart	No change

On the basis of these results it was decided that lane lines should be painted on all narrow roads. Do you think this was the best decision? Give your reasons for agreeing or disagreeing.

Agree: _________

Disagree: _________

Reason: ____

Scoring and comments on Science Example 2.2

Full Credit

Code 1: Answers that agree or disagree with the decision for reasons that are consistent with the given information. For example:

- agree because there is less chance of collisions if the traffic is keeping near the edges of the road, even if it is moving faster;
- agree because if traffic is moving faster, there is less incentive to overtake;
- disagree because if the traffic is moving faster and keeping the same distance apart, this may mean that the drivers don't have enough room to stop in an emergency.

No Credit

Code 0: Answers that agree or disagree without specifying the reasons, or provide reasons unrelated to the problem.

***Item type**: Open-constructed response*

***Process**: Interpreting scientific evidence and conclusions (Process 3)*

***Concept**: Forces and movement*

***Situation**: Science in technology*

Science Example 2.3

Drivers are advised to leave more space between their vehicles and the ones in front when they are travelling more quickly than when they are travelling more slowly because faster cars take longer to stop.

Explain why a faster car can take more distance to stop than a slower one.

Reasons: ____

Scoring and comments on Science Example 2.3

Full Credit

Code 2: Answers that mention that:

- the greater momentum of a vehicle when it is moving more quickly means that it will move further whilst slowing down than a slower vehicle, given the same force;

AND

- it takes longer to reduce speed to zero from a greater speed, so the car will travel further in this time.

Partial Credit

Code 1: Answers that mention only one of the above points.

No Credit

Code 0: Other responses, or repetition of the statement, *e.g.* that it takes longer to stop because of its speed.

Item type: *Open constructed-response*
Process: *Describing, explaining and predicting scientific phenomena (Process 1)*
Concept: *Forces and movement*
Situation: *Science in technology*

Science Example 2.4

Watching his TV, Peter sees one car A travelling at 45 km/h being overtaken by another car B travelling at 60 km/h. How fast does car B appear to be travelling to someone in car A?

A. 0 km/h

B. 15 km/h

C. 45 km/h

D. 60 km/h

E. 105 km/h

Scoring and comments on Science Example 2.4

Full Credit

Code 1: Response B: 15 km/h

No Credit

Code 0: Other responses.

Item type: *Multiple-choice*
Process: *Describing, explaining and predicting scientific phenomena (Process 1)*
Concept: *Forces and movement*
Situation: *Science in technology*

Science Unit 3

CORN

The following three items are from a unit entitled Corn. The stimulus material is a newspaper report about a man, Auke Ferwerda, who burns corn on his stove as a fuel.

> …Ferwerda points out that corn, in the form of cattle food, is in fact a type of fuel too. Cows eat corn to get energy out of it. But, Ferwerda explains, the sale of corn for fuel instead of for cattle food might be much more profitable for farmers.
>
> Ferwerda knows the environment is receiving increasing attention and government legislation to protect the environment is becoming increasingly elaborate. What Ferwerda does not quite understand is the amount of attention being focused on carbon dioxide. Carbon dioxide is regarded as the cause of the greenhouse effect. The greenhouse effect is said to be the main cause of the increasing average temperature of the Earth's atmosphere. In Ferwerda's view, however, there is nothing wrong with carbon dioxide. On the contrary, he argues, plants and trees absorb it and convert it into oxygen for human beings.
>
> He says: "This is an agricultural area and the farmers grow corn. It has a long growing season, absorbs a lot of carbon dioxide and emits a lot of oxygen. There are many scientists who say that carbon dioxide is not the main cause of the greenhouse effect".

Science Example 3.1

Ferwerda compares corn used as fuel to corn used as food.

The first column of the table below contains a list of things that happen when corn burns as a fuel.

Do these things also happen when corn acts as a fuel in an animal body?

Circle Yes or No for each.

When corn burns:	*Does this also happen when corn acts as a fuel in an animal body?*
Oxygen is consumed.	Yes / No
Carbon dioxide is produced.	Yes / No
Energy is produced.	Yes / No

Scoring and comments on Science Example 3.1

Full Credit

Code 1: Answers that specify Yes, Yes, Yes, in that order. (All parts have to be answered correctly, since any one error would indicate some failure in understanding the process of using food in an animal body).

No Credit

Code 0: Answers which specify any other combination of responses.

Item type: *Complex multiple-choice*
Process: *Describing, explaining and predicting scientific phenomena (Process 1)*
Concept: *Chemical and physical changes*
Situation: *Science in life and health*

Science Example 3.2

In the article a conversion of carbon dioxide is described: "…plants and trees absorb it and convert it into oxygen …".

There are more substances involved in this conversion than carbon dioxide and oxygen only. The conversion can be represented in the following way:

carbon dioxide + water ⟶ oxygen + ________________

Write in the box the name of the missing substance.

Scoring and comments on Science Example 3.2

Full Credit

Code 1: Answers that mention any one of the following: glucose; sugar; carbohydrate(s); saccharide(s); starch.

No Credit

Code 0: Other responses.

Item type: *Open constructed-response*
Process: *Describing, explaining and predicting scientific phenomena (Process 1)*
Concept: *Energy transformations*
Situation: *Science in life and health*

Science Example 3.3

At the end of the article Ferwerda refers to scientists who say that carbon dioxide is not the main cause of the greenhouse effect.

Karin finds the following table in which research results about the four most important gases causing the greenhouse effect are listed.

Relative greenhouse effect per molecule of gas			
Carbon dioxide	Methane	Nitrous oxide	Chlorofluorocarbons
1	30	160	17 000

From this table Karin concludes that carbon dioxide is not the main cause of the greenhouse effect. However this conclusion is premature. The data in the table need to be combined with other data to be able to conclude whether or not carbon dioxide is the main cause of the greenhouse effect. .

Which other data does Karin need to collect?

A. Data about the origin of the four gases.

B. Data about the absorption of the four gases by plants.

C. Data about the size of each of the four types of molecules.

D. Data about the amounts of each of the four gases in the atmosphere.

Scoring and comments on Science Example 3.3

There is a close relationship between the scientific knowledge that the concentration of a substance affects the extent of its action, and the recognition that a valid conclusion cannot be drawn without this extra information.

Full Credit

Code 1: Response D: Data about the amounts of each of the four gases in the atmosphere.

No Credit

Code 0: Other responses.

Item type: *Multiple-choice*
Process: *Interpreting scientific evidence and conclusions (Process 3)*
Concept: *Structure and properties of matter*
Situation: *Science in Earth and environment*

To answer all of these items the student is required to use knowledge that would be gained from the science curriculum and apply it in a novel situation. Where assessment of scientific understanding is not the main purpose of the item, the knowledge required is not the main challenge (or hurdle) and success should depend on ability in the particular process required. Where assessment of scientific understanding is the main aim, as in Science Examples 2.3, 2.4, 3.1 and 3.2, the process is one of demonstrating this understanding.

ASSESSMENT STRUCTURE

The test units incorporate up to about eight items, each independently scored. In the great majority of units, if not all, there are both items eliciting knowledge and understanding of the science involved, as in Science Examples 2.3 and 2.4 and 3.1 and 3.2, and items requiring use of one or more of the processes of

collecting and using evidence and data in a scientific investigation, as in Science Examples 1.1, 1.2, 2.1, 2.2 and 3.3. As indicated earlier, OECD/PISA does not include practical ("hands on") units, at least in the years 2000 and 2003, when science is a "minor" domain.

For the overall assessment, the desired balance between the processes is given in terms of percentages of scored points and shown in Figure 3.4. This may be revised for the assessment in 2006, when science will be the major domain of OECD/PISA.

Figure 3.4 ■ **Recommended distribution of scored points across science processes**

Scientific processes	Percentage of OECD/PISA science units
1. Describing, explaining and predicting scientific phenomena	40 – 50
2. Understanding scientific investigation	20 – 25
3. Interpreting scientific, evidence and conclusions	20 – 25
TOTAL	100

It may well be that the topics of some test units mean that the balance is tipped more towards assessment of understanding (Process 1), with the opposite occurring within other test units. Where possible, items assessing Processes 2 and 3 and items assessing Process 1 will occur within each unit. This is done both to achieve the aim of covering important scientific understanding that students are likely to have developed from their school science curricula or outside school, and because the ability to use processes is highly dependent upon the situation in which they are used. The aims of OECD/PISA suggest that both scientific knowledge and the combination of scientific knowledge with the ability to draw evidence-based conclusions are valued learning outcomes. The recommended target of roughly equal numbers of score points assigned to these two outcomes should serve these aims.

As already noted, all items will be concerned with the use of scientific knowledge that is likely to be developed in students through their school science curricula. Where the OECD/PISA science items differ from some – but by no means all – school science assessments is in their requirement that the knowledge be applied in real-life situations. Similarly, the ability to draw evidence-based conclusions appears among the aims of many school science curricula. The OECD/PISA assessment requires the application of the processes in situations that go beyond the school laboratory or classroom. The extent to which this is novel to students will depend on how far applications in the real world are part of the curriculum they have experienced.

Figure 3.5 ■ **Recommended distribution of scored points across areas of application**

Areas of application	**Percentage of OECD/PISA science units**
Science in life and health	30 – 40
Science in Earth and environment	30 – 40
Science in technology	30 – 40
TOTAL	100

In relation to the areas of application, Figure 3.5 shows that there will be as even a spread as possible across the three main groups.

A test unit is defined by a particular stimulus material, which may be a short written passage, or writing accompanying a table, chart, graph or diagram. The items are a set of independently scored questions requiring selection of a response in a multiple-choice format, a short open response or a long open response. The difference between short and long open response is that the latter require multiple marking whilst the former can be marked reliably by only one marker.

Up to the present, when science is a minor domain in the surveys, the number of units and items developed and field-tested is limited. However, based on this experience, we can summarise the test format for 2003:

- With one exception, units are extended, not single items; they include items assessing one or more of the scientific knowledge or context (Figure 3.1), scientific processes (Figure 3.2), and knowledge relating to one or more areas of application of science (Figure 3.3), and require answers on paper (writing or drawing).

- Units are presented in written form for 2003 as in 2000, although the use of stimuli in other forms will be investigated for the year 2006, when science is the major element.

- Some units involve reading and/or mathematics, but there are no items that require only identification of information from the stimulus material without some additional scientific processing, nor items that require only the recall of isolated factual information.

To cover the range of skills and understanding identified in this framework requires a range of item response formats. For example, multiple-choice items can be produced that validly assess those processes involving recognition or selection. However, for assessing the ability to evaluate and communicate, an open-response format is more likely to provide validity and authenticity. In many cases, however, the most appropriate format depends on the particular content of the item.

REPORTING SCALES

To meet the aims of OECD/PISA, the development of scales of student achievement is essential. The process of arriving at a scale has to be iterative, so that initial descriptions based on the results of the trials and the 2000 survey - and informed by past experience of assessing science achievement and findings from research into learning and cognitive development in science – are likely to be modified as more data are accumulated in further trials and surveys.

PISA 2000, when science was a minor domain and thus provided limited information, reported scientific literacy in terms of a proficiency scale with a mean of 500 and a standard deviation of 100. Although no proficiency levels were identified, it was possible to describe what students can do in three points in this scale:

- Towards the top end of the scientific literacy scale (around 690 points) students are generally able to create or use conceptual models to make predictions or give explanations; to analyse scientific investigations in order to grasp, for example, the design of an experiment or to identify an idea being tested; to compare data in order to evaluate alternative viewpoints or differing perspectives; and to communicate scientific arguments and/or descriptions in detail and with precision.
- At around 550 points, students are typically able to use scientific knowledge to make predictions or provide explanations; to recognise questions that can be answered by scientific investigation and/or identify details of what is involved in a scientific investigation; and to select relevant information from competing data or chains of reasoning in drawing or evaluating conclusions.
- Towards the lower end of the scale (around 400 points), students are able to recall simple factual scientific knowledge (*e.g.* names, facts, terminology, simple rules), and to use common scientific knowledge in drawing or evaluating conclusions.

In 2003, the reporting of science results is likely to follow a similar format. However, in the year 2006, when the testing time available will permit a wider coverage of scientific knowledge and areas of application, it may be possible, in addition to adding specific cut-points identifying proficiency levels, to report sub-scales for the processes in Figure 3.2. This will include, therefore, a sub-scale relating to scientific knowledge (Process 1) to be assessed by application in the situations presented.

In 2006 there may also be sufficient information available across the scientific processes listed in Figure 3.2 to consider reporting performance in the major fields of science. This will depend on statistical, conceptual and policy considerations. If it proves feasible to report sub-scales, countries will have the benefit of being able to compare the achieved outcomes of their science education in detail with what they consider desirable outcomes.

Reporting on the content of, and incorrect responses to, different items is an important accompaniment to item statistics. It is expected that these content categories will be generated from the field trial and related to the kinds of answers actually given by students. Reporting some types of answers to specific items will also be necessary in order to illustrate the scales and to give meaningful labels to them. This will involve releasing some items from those used in OECD/PISA.

Further levels of reporting are desirable and may become possible after the major science survey in 2006. One of these is performance in groups of items across units relating to the separate areas of application of science. This information will be useful in considering whether sufficient and effective attention is being given to issues of current concern.

OTHER ISSUES

When information for a scientific literacy assessment unit is presented in the form of an extended written passage, aspects of reading can be assessed. Similarly, when information is presented in the form of tables, charts, graphs, etc., the ability to read information can be assessed, and where some manipulation of number is required, certain aspects of mathematics can be assessed. Such units will form part of the combined packages of the survey. Other units will assess only scientific processes involving drawing evidence-based conclusions and demonstrating scientific understanding.

The surveys of science in the years 2000 and 2003, in which science is a "minor" element, form the basis for comparisons over time. The restriction on the number of assessment units in 2000 and 2003 (even within a survey design that allows different packages of items to be answered by different sub-samples of students) means that there are fewer units relating to each area of application of science than will be possible in 2006. Thus the minor surveys of scientific literacy involve the assessment of all the processes identified in Figure 3.2 and some of the scientific knowledge (concepts) and areas of application identified in Figures 3.1 and 3.3. In the major year for science, 2006, a far more comprehensive coverage of the scientific knowledge and areas of application will be possible.

