3

PISA 2012 Science Framework

This chapter presents the theory underlying the PISA 2012 science assessment. It begins with a definition of scientific literacy, outlines the organisation of science in PISA and sets the context for the test questions. The chapter describes the knowledge and skills at the heart of the assessment: *identifying scientific issues, explaining phenomena scientifically* and *using scientific evidence*. It then describes how knowledge and attitudes are also encompassed in the PISA definition of scientific literacy. Test questions are given as examples throughout this chapter to illustrate the classification, format and structure of the PISA science assessment.

INTRODUCTION

This framework describes and illustrates the definition of *scientific literacy* as used in PISA and sets the context for the items. Science is a minor domain in PISA 2012. The definition of the domain is unchanged since PISA 2006 when for the first time it was the major domain assessed (OECD, 2006; Bybee and McCrae, 2009), though there are some changes in terminology, which have been brought about by an attempt to better align the language used in PISA with the language used in the DeSeCo initiative (OECD, 2003).

In this framework, the term "science literacy" denotes an overarching competency comprising a set of three specific scientific competencies. A competency is more than just knowledge and skills (OECD, 2003). It includes the capacity to mobilise cognitive and non-cognitive resources in any given context. When discussing the cognitive dimensions of the specific scientific competencies, as is pertinent to the PISA science assessment in the current cycle, reference is made to the relevant scientific knowledge and skills demonstrated by students. However, the sub-scales of the PISA science scale as established in PISA 2006 (OECD, 2006) are still referred to as scientific competencies.

In keeping with its status as a minor domain in this cycle, the student questionnaire will not include items asking about students' general attitudes towards science; nor will the main assessment instrument include questions on attitudes alongside the testing of cognitive abilities and knowledge, as was the case in PISA 2006. In this revised version of the science framework for PISA 2012, like for PISA 2009, the section describing the PISA science assessment has been revised to reflect these changes, the discussion on reporting scales has been updated, and released examples from PISA 2006 have been included to illustrate the framework.

An understanding of science and technology is central to a young person's preparedness for life in modern society. It enables an individual to participate fully in a society in which science and technology play a significant role. This understanding also empowers individuals to participate appropriately in the determination of public policy where issues of science and technology impact on their lives. An understanding of science and technology contributes significantly to the personal, social, professional and cultural lives of everyone.

A large proportion of the situations, problems and issues encountered by individuals in their daily lives require some understanding of science and technology before they can be fully understood or addressed. Science and technology related issues confront individuals at personal, community, national and even global levels. Therefore, national leaders should be encouraged to ask about the degree to which all individuals in their respective countries are prepared to deal with these issues. A critical aspect of this is how young people respond to scientific questions when they emerge from school. An assessment at age 15 provides an early indication of how students may respond later in life to the diverse array of situations that involve science and technology.

As the basis for an international assessment of 15-year-old students, it seems reasonable, therefore, to ask: "What is it important for citizens to know, value, and be able to do in situations involving science and technology?" Answering this question establishes the basis for an assessment of students with regards to how their knowledge, values and abilities today relate to what they will need in the future. Central to the answer are the competencies that lie at the heart of the PISA science assessment. These ask how well students:

- *identify scientific issues;*
- *explain phenomena scientifically*; and
- *use scientific evidence*.

These competencies require students to demonstrate, on the one hand, knowledge and cognitive abilities, and on the other, attitudes, values and motivations, as they meet and respond to science-related issues.

The issue of identifying what citizens should know, value and be able to do in situations involving science and technology, seems simple and direct. However, doing so raises questions about scientific understanding and does not imply mastery of all scientific knowledge. This framework is guided by reference to what citizens require. As citizens, what knowledge is most appropriate? An answer to this question certainly includes basic concepts of the science disciplines, but that knowledge must be used in contexts that individuals encounter in life. In addition, people often encounter situations that require some understanding of science as a process that produces knowledge and proposes explanations about the natural world.[1] Further, they should be aware of the complementary relationships between science and technology, and how science-based technologies pervade and influence the nature of modern life.

What is important for citizens to value about science and technology? An answer should include the role and contributions to society of science and of science-based technology, and their importance in many *personal*, *social*, and *global* contexts. Accordingly, it seems reasonable to expect individuals to have an interest in science, to support the process of scientific enquiry and to act responsibly towards natural resources and the environment.

What is important for individuals to be able to do that is science-related? People often have to draw appropriate conclusions from evidence and information given to them; they have to evaluate claims made by others on the basis of the evidence put forward and they have to distinguish personal opinion from evidence-based statements. Often the evidence involved is scientific, but science has a more general role to play as well since it is concerned with rationality in testing ideas and theories against evidence. Of course this does not deny that science includes creativity and imagination, attributes that have always played a central part in advancing human understanding of the world.

Can citizens distinguish claims that are scientifically sound from those that are not? Ordinary citizens are generally not called on to judge the worth of major theories or potential advances in science. But they do make decisions based on the facts in advertisements, evidence in legal matters, information about their health, and issues concerning local environments and natural resources. An educated person should be able to distinguish the kinds of questions that can be answered by scientists and the kinds of problems that can be solved by science-based technologies from those that cannot be answered in these ways.

DEFINING SCIENTIFIC LITERACY

Current thinking about the desired outcomes of science education emphasises scientific knowledge (including knowledge of the scientific approach to enquiry) and an appreciation of science's contribution to society. These outcomes require an understanding of important concepts and explanations of science, and of the strengths and limitations of science in the world. They imply a critical stance and a reflective approach to science (Millar and Osborne, 1998).

Such goals provide an orientation and emphasis for the science education of all people (Fensham, 1985). The competencies assessed in PISA are broad and include aspects that relate to personal utility, social responsibility, and the intrinsic and extrinsic value of scientific knowledge.

The above discussion frames a central point of the PISA science assessment: the assessment should focus on scientific competencies that clarify what 15-year-old students know, value and are able to do within reasonable and appropriate *personal*, *social*, and *global* contexts. This perspective differs from one grounded exclusively in school science programmes and extensively based only on the disciplines of science; but it includes problems situated in educational contexts and also in professional ones, and recognises the essential place of the knowledge, methods, attitudes, and values that define scientific disciplines (Bybee, 1997a; Fensham, 2000; Gräber and Bolte, 1997; Mayer, 2002; Roberts, 1983; UNESCO, 1993).

PISA is concerned with both the cognitive and affective aspects of students' competencies in science. The cognitive aspects include students' knowledge and their capacity to use this knowledge effectively, as they carry out certain cognitive processes that are characteristic of science and scientific enquiries of *personal*, *social*, and *global* relevance. In assessing scientific competencies, PISA is concerned with issues to which scientific knowledge can contribute and which will involve students, either now or in the future, in making decisions. From the point of view of their scientific competencies, students respond to such issues in terms of their understanding of relevant scientific knowledge, their ability to access and evaluate information, their ability to interpret evidence bearing on the issue and their ability to identify the scientific and technological aspects of the issue (Koballa et al., 1997; Law, 2002). PISA also is concerned with non-cognitive aspects: how students respond affectively. Attitudinal aspects of their response engage their interest, sustain their support, and motivate them to take action (Schibeci, 1984).

Box 3.1 **Scientific knowledge: PISA terminology**

The term "scientific knowledge" is used throughout this framework to refer to both *knowledge of science* and *knowledge about science*. *Knowledge of science* refers to knowledge of the natural world across the major fields of physics, chemistry, biological science, Earth and space science, and science-based technology. *Knowledge about science* refers to knowledge of the means ("scientific enquiry") and goals ("scientific explanations") of science.

The PISA science assessment encompasses a continuum of scientific knowledge and the cognitive abilities associated with scientific enquiry, incorporates multiple dimensions, and addresses the relationships between science and technology. It provides an assessment of students' scientific literacy by assessing their capacity to use scientific knowledge (Bybee, 1997b; Fensham, 2000; Law, 2002; Mayer and Kumano, 2002).

Box 3.2 **PISA scientific literacy**

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

- Scientific knowledge and use of that knowledge to identify questions, acquire new knowledge, explain scientific phenomena and 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.
- Willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

Explanation of the definition

The following remarks clarify the definition of scientific literacy as defined for the purposes of PISA.

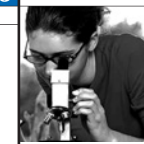
Using the term "scientific literacy" rather than "science" underscores the importance that the PISA science assessment places on the application of scientific knowledge in the context of life situations, compared with the simple reproduction of traditional school science knowledge. The functional use of knowledge requires the application of those processes that are characteristic of science and scientific enquiry (here termed the scientific competencies) and is regulated by the individual's appreciation, interest, values, and action relative to scientific matters. A student's ability to carry out the scientific competencies involves both *knowledge of science* and an understanding of the characteristics of science as a way of acquiring knowledge (i.e. *knowledge about science*). The definition also recognises that the disposition to carry out these competencies depends upon an individual's attitudes towards science and a willingness to engage in science-related issues.

Knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena and to draw evidence-based conclusions

"Knowledge" for this definition implies far more than the ability to recall information, facts, and names. The definition includes *knowledge of science* (knowledge about the natural world) and *knowledge about science* itself. *Knowledge of science* includes understanding fundamental scientific concepts and theories; *knowledge about science* includes understanding the nature of science as a human activity and the power and limitations of scientific knowledge. The questions to be identified are those that can be answered by scientific enquiry, again requiring *knowledge about science* as well as scientific knowledge of the specific topics involved. Of significance is that individuals must often acquire new knowledge not through their own scientific investigations, but through resources such as libraries and the Internet. Drawing evidence-based conclusions means knowing, selecting and evaluating information and data, while 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.

Characteristic features of science as a form of human knowledge and enquiry

As expressed here, being scientifically literate implies that students should have some understanding of how scientists obtain data and propose explanations, and recognise key features of scientific investigations and the types of answers one can reasonably expect from science. For example, scientists use observations and experiments to gather data about objects, organisms and events in the natural world. The data are used to propose explanations that become public knowledge and may be used in various forms of human activity. Some key features of science include: the collection and use of data – data collection is guided by ideas and concepts (sometimes stated as hypotheses) and includes issues of relevance, context and accuracy; the tentative nature of knowledge claims; an openness to sceptical review; the use of logical arguments; and, the obligation to make connections to current and historical knowledge, and to report the methods and procedures used in obtaining evidence.



How science and technology shape our material, intellectual, and cultural environments

The key points in this statement include the idea that science is a human endeavour, one that influences our societies and us as individuals. Further, technological development is also a human endeavour (Fleming, 1989). Although science and technology differ in aspects of their purposes, processes, and products, they are also closely related and, in many respects, complementary. In this regard, the definition of scientific literacy as used here includes the nature of science and of technology and their complementary relationships. As individuals we make decisions through public policies that influence the directions of science and technology. Science and technology play paradoxical roles in society as they propose answers to questions and provide solutions to problems, but may also create new questions and problems.

Willingness to engage in science-related issues and with the ideas of science as a reflective citizen

The meaning conveyed in the first part of this statement, 'willingness to engage in science-related issues', is wider than taking note and taking action as required; it implies having continuing interest in, having opinions about and participating in current and future science-based issues. The second part of the statement, 'with the ideas of science as a reflective citizen', covers various aspects of attitudes and values that individuals may have towards science. The whole phrase implies a person who has an interest in scientific topics, thinks about science-related issues, is concerned about issues of technology, resources and the environment, and reflects on the importance of science in personal and social perspectives.

Inevitably, scientific competencies draw upon reading and mathematical competencies (Norris and Phillips, 2003). For example, aspects of mathematical competencies are required in data interpretation contexts. Similarly, reading literacy is necessary when a student is demonstrating an understanding of scientific terminology. The intersection of these other domains with the PISA definition and assessment of science cannot be avoided; however, at the core of each assessment task there should be aspects that relate unambiguously to science competency.

ORGANISING THE DOMAIN

The definition of the science domain proposed here provides for a continuum in which individuals are deemed to be more or less scientifically literate; they are not regarded as either scientifically literate or scientifically illiterate (Bybee, 1997a; 1997b). So, for example, the student with less developed scientific literacy might be able to recall simple scientific factual knowledge and to use common scientific knowledge in drawing or evaluating conclusions. A student with more developed scientific literacy will demonstrate the ability to create and use conceptual models to make predictions and give explanations, analyse scientific investigations, relate data as evidence, evaluate alternative explanations of the same phenomena, and communicate conclusions with precision.

For assessment purposes, the PISA definition of *scientific literacy* may be characterised as consisting of four interrelated aspects (see Figure 3.1):

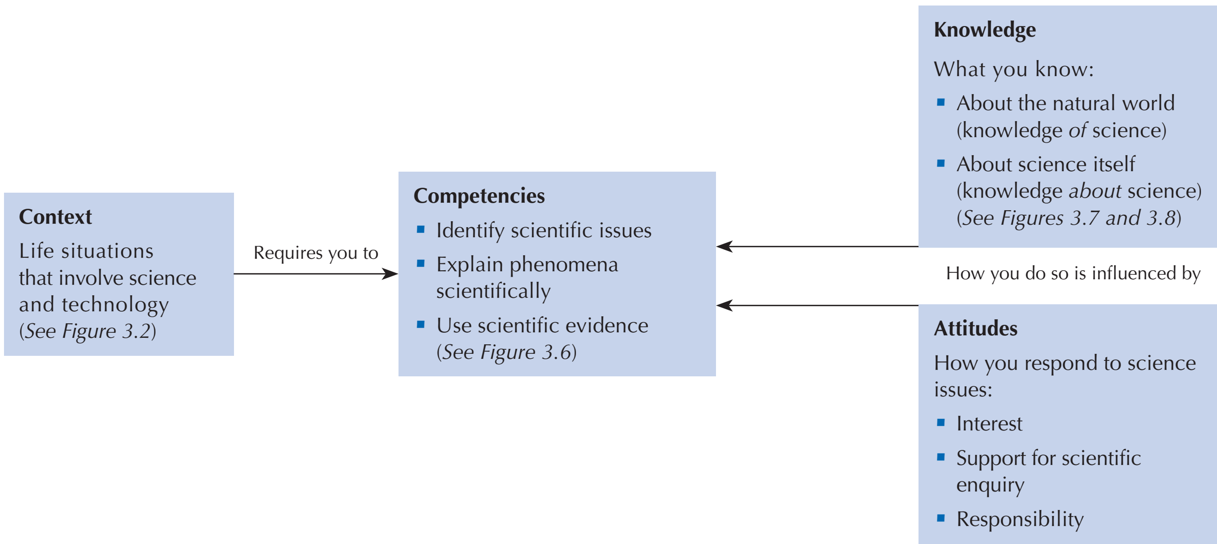
- Context: recognising life situations involving science and technology.
- Knowledge: understanding the natural world on the basis of scientific knowledge that includes both knowledge of the natural world, and *knowledge about science* itself.
- Competencies: demonstrating scientific competencies that include *identifying scientific issues, explaining phenomena scientifically*, and *using scientific evidence*.
- Attitudes: indicating an interest in science, support for scientific enquiry, and motivation to act responsibly towards, for example, natural resources and environments.

The following sections restate and elaborate these interrelated aspects. In highlighting these aspects, the PISA science framework has ensured that the focus of the assessment is upon the outcomes of science education. Several questions have guided the establishment of the PISA science framework. They are:

- What contexts would be appropriate for assessing 15-year-old students?
- What competencies might we reasonably expect 15-year-old students to demonstrate?
- What knowledge might we reasonably expect 15-year-old students to demonstrate?
- What attitudes might we reasonably expect 15-year-old students to demonstrate?

■ Figure 3.1 ■

Framework for the PISA science assessment



Situations and context

An important aspect of the PISA science assessment is engagement with science in a variety of situations. In dealing with scientific issues, the choice of methods and representations is often dependent on the situations in which the issues are presented.

The situation is the part of the student's world in which the tasks are placed. Assessment items are framed in situations of general life and not limited to life in school. In the PISA science assessment, the focus of the items is on situations relating to the self, family and peer groups (*personal*), to the community (*social*) and to life across the world (*global*). 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.

PISA assesses important scientific knowledge relevant to the science education curricula of participating countries without being constrained to the common aspects of participants' national curricula. The assessment does this by requiring evidence of the successful use of science knowledge and skills in important situations reflecting the world and in accordance with the PISA focus. This, in turn, involves the application of selected knowledge about the natural world, and about science itself, and evaluation of students' attitudes towards scientific matters.

Figure 3.2 lists the main applications of science that are involved within *personal*, *social*, and *global* settings as the contexts, or specific situations, for assessment exercises. However, other settings (e.g. technological, historical) and areas of application are also used. The areas of application are: "health", "natural resources", "the environment", "hazards", and "the frontiers of science and technology". They are the areas in which science has particular value for individuals and communities in enhancing and sustaining quality of life, and in the development of public policy.

The PISA science assessment is not an assessment of contexts. It assesses competencies, knowledge and attitudes as these are presented or relate to contexts. In selecting the contexts, it is important to keep in mind that the purpose of the assessment is to assess scientific competencies, understandings, and attitudes that students have acquired by the end of the compulsory years of schooling.

PISA items are arranged in groups (units) based around a common stimulus that establishes the context for the items. The contexts used are chosen in the light of relevance to students' interests and lives. The items are developed keeping in mind linguistic and cultural differences in participating countries.

■ Figure 3.2 ■
Contexts for the PISA science assessment

	Personal (self, family and peer groups)	Social (the community)	Global (life across the world)
Health	Maintenance of health, accidents, nutrition	Control of disease, social transmission, food choices, community health	Epidemics, spread of infectious diseases
Natural resources	Personal consumption of materials and energy	Maintenance of human populations, quality of life, security, production and distribution of food, energy supply	Renewable and non-renewable energy sources, natural systems, population growth, sustainable use of species
Environment	Environmentally friendly behaviour, use and disposal of materials	Population distribution, disposal of waste, environmental impact, local weather	Biodiversity, ecological sustainability, control of pollution, production and loss of soil
Hazard	Natural and human-induced, decisions about housing	Rapid changes (earthquakes, severe weather), slow and progressive changes (coastal erosion, sedimentation), risk assessment	Climate change, impact of modern warfare
Frontiers of science and technology	Interest in science's explanations of natural phenomena, science-based hobbies, sport and leisure, music and personal technology	New materials, devices and processes, genetic modification, weapons technology, transport	Extinction of species, exploration of space, origin and structure of the universe

Illustrative PISA science items

In this section, three examples of science units from the PISA 2006 assessment are presented. They are referred to throughout the remainder of the chapter to illustrate the variety of contexts involved, the scientific competencies and areas of scientific knowledge addressed by PISA science items, and the item types (formats) employed. In addition, the scoring guide for each item is shown (for a description of proficiency levels, see Figure 3.10).

ACID RAIN

In this example, the stimulus material is a photograph of statues on the Acropolis in Athens, together with a brief statement explaining that the original statues were moved inside the museum of the Acropolis due to their deterioration from acid rain. The area of application is "Hazards" within *personal* and *social* settings.

■ Figure 3.3 ■
Items for the unit *ACID RAIN*

Below is a photo of statues called Caryatids that were built on the Acropolis in Athens more than 2500 years ago. The statues are made of a type of rock called marble. Marble is composed of calcium carbonate.

In 1980, the original statues were transferred inside the museum of the Acropolis and were replaced by replicas. The original statues were being eaten away by acid rain.

QUESTION 1

Normal rain is slightly acidic because it has absorbed some carbon dioxide from the air. Acid rain is more acidic than normal rain because it has absorbed gases like sulfur oxides and nitrogen oxides as well.

Where do these sulfur oxides and nitrogen oxides in the air come from?

Full credit (Level 3: 506)

Any one of car exhausts, factory emissions, *burning* fossil fuels such as oil and coal, gases from volcanoes or other similar things *OR* Responses that include an incorrect as well as a correct source of the pollution *OR* Responses that refer to "pollution" but do not give a source of pollution that is a significant cause of acid rain.

The effect of acid rain on marble can be modelled by placing chips of marble in vinegar overnight. Vinegar and acid rain have about the same acidity level. When a marble chip is placed in vinegar, bubbles of gas form. The mass of the dry marble chip can be found before and after the experiment.

QUESTION 2

A marble chip has a mass of 2.0 grams before being immersed in vinegar overnight. The chip is removed and dried the next day.

What will the mass of the dried marble chip be?

A. Less than 2.0 grams

B. Exactly 2.0 grams

C. Between 2.0 and 2.4 grams

D. More than 2.4 grams

Full credit (Level 2: 460)

A. Less than 2.0 grams

QUESTION 3

Students who did this experiment also placed marble chips in pure (distilled) water overnight.

Explain why the students included this step in their experiment.

Full credit (Level 6: 717)

To show that the acid (vinegar) is necessary for the reaction.

Partial credit (Level 3: 513)

To compare with the test of vinegar and marble, but it is not made clear that this is being done to show that the acid (vinegar) is necessary for the reaction.

GREENHOUSE

This unit deals with the increase of the average temperature of the Earth's atmosphere. The stimulus material consists of a short text introducing the term "Greenhouse effect" and includes graphical information on the average temperature of the Earth's atmosphere and the carbon dioxide emission on the Earth over time.

The area of application is "Environment" within a *global* setting.

■ Figure 3.4 ■

Items for the unit *GREENHOUSE*

Read the texts and answer the questions that follow.

THE GREENHOUSE EFFECT: FACT OR FICTION?

Living things need energy to survive. The energy that sustains life on the Earth comes from the Sun, which radiates energy into space because it is so hot. A tiny proportion of this energy reaches the Earth.

The Earth's atmosphere acts like a protective blanket over the surface of our planet, preventing the variations in temperature that would exist in an airless world.

Most of the radiated energy coming from the Sun passes through the Earth's atmosphere. The Earth absorbs some of this energy, and some is reflected back from the Earth's surface. Part of this reflected energy is absorbed by the atmosphere.

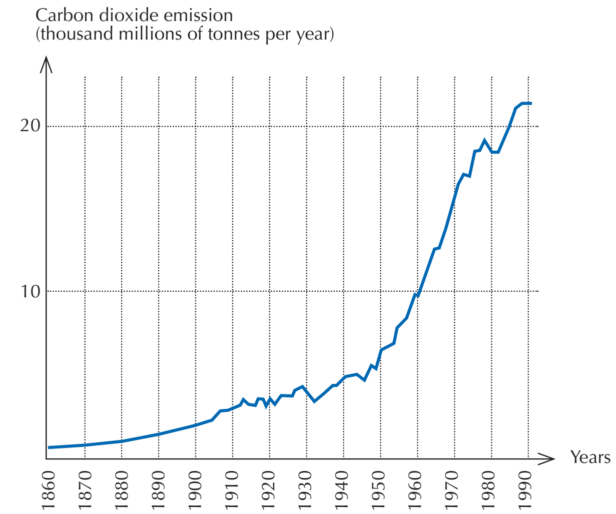
As a result of this the average temperature above the Earth's surface is higher than it would be if there were no atmosphere. The Earth's atmosphere has the same effect as a greenhouse, hence the term greenhouse effect.

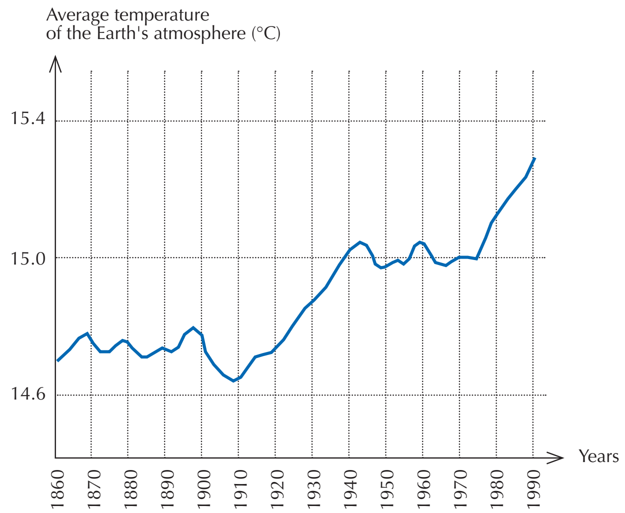
The greenhouse effect is said to have become more pronounced during the twentieth century.

It is a fact that the average temperature of the Earth's atmosphere has increased. In newspapers and periodical the increased carbon dioxide emission is often stated as the main source of the temperature rise in the twentieth century.

A student named André becomes interested in the possible relationship between the average temperature of the Earth's atmosphere and the carbon dioxide emission on the Earth.

In a library he comes across the following two graphs.





André concludes from these two graphs that it is certain that the increase in the average temperature of the Earth's atmosphere is due to the increase in the carbon dioxide emission.

QUESTION 1

What is it about the graphs that supports André's conclusion?

....

Full credit (Level 3: 529)

Refers to the increase of both (average) temperature and carbon dioxide emission OR Refers (in general terms) to a positive relationship between temperature and carbon dioxide emission.

QUESTION 2

Another student, Jeanne, disagrees with André's conclusion. She compares the two graphs and says that some parts of the graphs do not support his conclusion.

Give an example of a part of the graphs that does not support André's conclusion. Explain your answer.

....

Full credit (Level 5: 659)

Refers to one particular part of the graphs in which the curves are not both descending or both climbing and gives the corresponding explanation.

Partial credit (Level 4: 568)

Mentions a correct period, without any explanation OR Mentions only one particular year (not a period of time), with an acceptable explanation OR Gives an example that doesn't support André's conclusion but makes a mistake in mentioning the period OR Refers to differences between the two curves, without mentioning a specific period OR Refers to an irregularity in one of the graphs OR Indicates difference in the graphs, but explanation is poor.

QUESTION 3

André persists in his conclusion that the average temperature rise of the Earth's atmosphere is caused by the increase in the carbon dioxide emission. But Jeanne thinks that his conclusion is premature. She says: "Before accepting this conclusion you must be sure that other factors that could influence the greenhouse effect are constant".

Name one of the factors that Jeanne means.

....

Full credit (Level 6: 709)

Gives a factor referring to the energy/radiation coming from the Sun OR Gives a factor referring to a natural component or a potential pollutant.

PHYSICAL EXERCISE

This unit is concerned with the effect of physical exercise on personal health.

■ Figure 3.5 ■

Items for the unit *PHYSICAL EXERCISE*

Regular but moderate physical exercise is good for our health.

QUESTION 1

What are the advantages of regular physical exercise? Circle "Yes" or "No" for each statement.

Is this an advantage of regular physical exercise?	Yes or No ?
Physical exercise helps prevent heart and circulation illnesses.	Yes / No
Physical exercise leads to a healthy diet.	Yes / No
Physical exercise helps to avoid becoming overweight.	Yes / No

Full credit (Level 3: 545)

All three correct: Yes, No, Yes in that order.

QUESTION 2

What happens when muscles are exercised? Circle "Yes" or "No" for each statement.

Does this happen when muscles are exercised?	Yes or No ?
Muscles get an increased flow of blood.	Yes / No
Fats are formed in the muscles.	Yes / No

Full credit (Level 1: 386)

Both correct: Yes, No in that order.

QUESTION 3

Why do you have to breathe more heavily when you're doing physical exercise than when your body is resting?

....

Full credit (Level 4: 583)

To remove increased levels of carbon dioxide and to supply more oxygen to your body OR To remove increased levels of carbon dioxide from your body OR To supply more oxygen to your body, but not both.

Scientific competencies

The PISA science assessment gives priority to the competencies listed in Figure 3.6: the ability to identify scientifically-oriented issues; describe, explain or predict phenomena based on scientific knowledge; interpret evidence and conclusions, and use scientific evidence to make and communicate decisions. Demonstrating these competencies in the PISA assessment involves applying scientific knowledge – both *knowledge of science* and *knowledge about science* itself as a form of knowledge and an approach to enquiry.

■ Figure 3.6 ■

PISA scientific competencies

Identifying scientific issues
- Recognising issues that are possible to investigate scientifically
- Identifying keywords to search for scientific information
- Recognising the key features of a scientific investigation

Explaining phenomena scientifically
- Applying knowledge of science in a given situation
- Describing or interpreting phenomena scientifically and predicting changes
- Identifying appropriate descriptions, explanations, and predictions

Using scientific evidence
- Interpreting scientific evidence and making and communicating conclusions
- Identifying the assumptions, evidence and reasoning behind conclusions
- Reflecting on the societal implications of science and technological developments

Some cognitive processes have special meaning and relevance for *scientific literacy*. Among the cognitive processes that are implied in the scientific competencies are: inductive reasoning (reasoning from detailed facts to general principles) and deductive reasoning (reasoning from the general to the particular), critical and integrated thinking, transforming representations (e.g. data to tables, tables to graphs), constructing and communicating arguments and explanations based on data, thinking in terms of models, and using mathematical processes, knowledge and skills.

Justification for an emphasis on the scientific competencies of Figure 3.6 in PISA rests on the importance of these competencies for scientific investigation. They are grounded in logic, reasoning, and critical analysis. An elaboration of the scientific competencies follows, including references to how they are assessed in the science examples presented in the previous section.

Identifying scientific issues

It is important to be able to distinguish scientific issues and content from other forms of issues. Importantly, scientific issues must lend themselves to answers based on scientific evidence. The competency *identifying scientific issues* includes recognising questions that it would be possible to investigate scientifically in a given situation and identifying keywords to search for scientific information on a given topic. It also includes recognising key features of 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.

Identifying scientific issues requires students to possess *knowledge about science* itself, and may also draw, to varying degrees, on their *knowledge of science*. For example, Question 3 of *ACID RAIN* requires students to answer a question about the control in a scientific investigation. Students must compare an acid (vinegar) reaction to possible reactions with pure water to be sure that acid is the cause of the reaction.

Explaining phenomena scientifically

Demonstrating the competency *explaining phenomena scientifically* involves applying appropriate *knowledge of science* in a given situation. The competency includes describing or interpreting phenomena and predicting changes, and may involve recognising or identifying appropriate descriptions, explanations, and predictions. An example of a PISA item that requires students to explain phenomena scientifically is Question 1 of *ACID RAIN*, where students must explain the origin of sulfur oxides and nitrogen oxides in the air. Other examples are: Question 3 of *GREENHOUSE*, which requires students to identify factors causing the average temperature rise of the Earth, and Question 3 of *PHYSICAL EXERCISE* which asks students to apply their knowledge of the human respiratory system.

Using scientific evidence

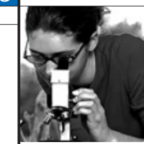
The competency *using scientific evidence* includes accessing scientific information and producing arguments and conclusions based on scientific evidence (Kuhn, 1992; Osborne et al., 2001). The required response can involve *knowledge about science* or *knowledge of science* or both. Question 2 of *ACID RAIN* requires students to use the information provided to form a conclusion about the effects of vinegar on marble, a simple model for the influence of acid rain on marble. Other examples are Questions 1 and 2 of *GREENHOUSE*, both of which require students to interpret evidence presented in two graphs.

The competency also involves: selecting from alternative conclusions in relation to evidence; giving reasons for or against a given conclusion in terms of the process by which the conclusion was derived from the data provided; and identifying the assumptions made in reaching a conclusion. Reflecting on the societal implications of scientific or technological developments is another aspect of this competency.

Students may be required to express their evidence and decisions to a specified audience, through their own words, diagrams or other representations as appropriate. In short, students should be able to present clear and logical connections between evidence and conclusions or decisions.

Scientific knowledge

As previously noted (see Box 3.1), scientific knowledge refers to both *knowledge of science* (knowledge about the natural world) and *knowledge about science* itself.



Knowledge of science

Given that only a sample of students' *knowledge of science* can be assessed in any one PISA assessment, it is important that clear criteria are used to guide the selection of knowledge that is assessed. Moreover, the objective of PISA is to describe the extent to which students can apply their knowledge in contexts of relevance to their lives. Accordingly, the assessed knowledge will be selected from the major fields of physics, chemistry, biology, Earth and space science, and technology according to the following criteria:

- The relevance to real-life situations: scientific knowledge differs in the degree to which it is useful in the life of individuals.
- The knowledge selected represents important scientific concepts and thus has enduring utility.
- The knowledge selected is appropriate to the developmental level of 15-year-old students.

Figure 3.7 shows the *knowledge of science* categories and examples of content selected by applying these criteria. This knowledge is required for understanding the natural world and for making sense of experiences in *personal*, *social* and *global* situations. The framework uses the term "systems" instead of "sciences" in the descriptors of the major fields to convey the idea that citizens have to apply their understanding of concepts from the physical and life sciences, Earth and space science, and technology, in situations that interact in more or less united ways.

■ Figure 3.7 ■

PISA categories of knowledge of science

Physical systems
- Structure of matter (e.g. particle model, bonds)
- Properties of matter (e.g. changes of state, thermal and electrical conductivity)
- Chemical changes of matter (e.g. reactions, energy transfer, acids/bases)
- Motions and forces (e.g. velocity, friction)
- Energy and its transformation (e.g. conservation, dissipation, chemical reactions)
- Interactions of energy and matter (e.g. light and radio waves, sound and seismic waves)

Living systems
- Cells (e.g. structures and function, DNA, plant and animal)
- Humans (e.g. health, nutrition, subsystems [i.e. digestion, respiration, circulation, excretion, and their relationship], disease, reproduction)
- Populations (e.g. species, evolution, biodiversity, genetic variation)
- Ecosystems (e.g. food chains, matter and energy flow)
- Biosphere (e.g. ecosystem services, sustainability)

Earth and space systems
- Structures of Earth systems (e.g. lithosphere, atmosphere, hydrosphere)
- Energy in Earth systems (e.g. sources, global climate)
- Change in Earth systems (e.g. plate tectonics, geochemical cycles, constructive and destructive forces)
- Earth's history (e.g. fossils, origin and evolution)
- Earth in space (e.g. gravity, solar systems)

Technology systems
- Role of science-based technology (e.g. solve problems, help humans meet needs and wants, design and conduct investigations)
- Relationships between science and technology (e.g. technologies contribute to scientific advancement)
- Concepts (e.g. optimisation, trade-offs, cost, risk, benefit)
- Important principles (e.g. criteria, constraints, innovation, invention, problem solving)

The examples listed in Figure 3.7 convey the meanings of the categories; there is no attempt to list comprehensively all the knowledge that could be related to each of the *knowledge of science* categories.

Question 2 of *ACID RAIN* assesses students' *knowledge of science* in the category "Physical systems".

Question 3 of *GREENHOUSE* is concerned with students' knowledge of "Earth and space systems"; and Questions 1, 2 and 3 of *PHYSICAL EXERCISE* assess students' knowledge of "Living systems".

Knowledge about science

Figure 3.8 displays the categories and examples of content for *knowledge about science*. The first category, “Scientific enquiry,” centres on enquiry as the central process of science and the various components of that process. The second category, closely related to enquiry, is “Scientific explanations”. “Scientific explanations” are the results of “Scientific enquiry”. One can think of enquiry as the means of science (how scientists get data) and explanations as the goals of science (how scientists use data). The examples listed in Figure 3.8 convey the general meanings of the categories; there is no attempt to list comprehensively all the knowledge that could be related to each category.

■ Figure 3.8 ■

PISA categories of knowledge about science

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)

Question 3 of *ACID RAIN* is an example of *knowledge about science* in the category “Scientific enquiry” but assumes some *knowledge of science* (category “Physical systems”) that students can be expected to possess. The question requires students to identify the possible purposes for a control of an investigation (competency: *Identifying Scientific Issues*).

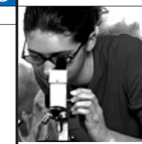
Questions 1 and 2 of *GREENHOUSE* are *knowledge about science* items. Both of these items belong to the category “Scientific explanations”. In Question 1, students must interpret evidence presented in two graphs and argue that the graphs together support an explanation that an increase in the Earth’s average temperature is due to an increase in carbon dioxide emissions. Question 2 asks students to use evidence from the same graphs to support a different conclusion.

Attitudes towards science

Individuals’ attitudes play a significant role in their interest and response to science and technology in general and to issues that affect them in particular. One goal of science education is for students to develop attitudes that make them likely to attend to scientific issues and subsequently to acquire and apply scientific and technological knowledge for *personal*, *social*, and *global* benefit.

PISA attention to attitudes towards science is based on the belief that a person’s scientific literacy includes certain attitudes, beliefs, motivational orientations, sense of self-efficacy, values, and ultimate actions. This is supported by and builds upon Klopfer’s (1976) structure for the affective domain in science education, as well as reviews of attitudinal research (for example, Gardner, 1975, 1984; Gauld and Hukins, 1980; Blosser, 1984; Laforgia, 1988; Osborne et al., 2003; Schibeci, 1984) and research into students’ attitudes towards the environment (for example, Bogner and Wiseman, 1999; Eagles and Demare, 1999; Weaver, 2002; Rickinson, 2001).

In PISA 2006, when science was the major domain assessed, an assessment of students’ attitudes and values was included using the student questionnaire and through contextualised questions posed immediately after the test questions in many units (OECD, 2006). These contextualised questions were related to the issues addressed in the test questions. However, since science constitutes a minor part of the assessment in PISA 2012, the assessment will not contain any contextualised (embedded) attitudinal items.



ASSESSING SCIENTIFIC LITERACY

Test characteristics

In accordance with the PISA definition of scientific literacy, test questions (items) require the use of the scientific competencies (see Figure 3.6) within a context (see Figure 3.2). This involves the application of scientific knowledge (see Figures 3.7 and 3.8).

Figure 3.9 is a variation of Figure 3.1 that presents the basic components of the PISA framework for science assessment in a way that can be used to relate the framework with the structure and the content of assessment units. Figure 3.9 may be used both synthetically as a tool to plan assessment exercises, and analytically as a tool to study the results of standard assessment exercises. As a starting point to construct assessment units, we could consider the contexts that would serve as stimulus material, the scientific competencies required to respond to the questions or issues, or the scientific knowledge central to the exercise.

A test unit is comprised of a group of independently scored questions (items) of various types, accompanied by stimulus material that establishes the context for the items. Many different types of stimulus are used, often in combination, to establish the context, including passages of text, photographs, tables, graphs, and diagrams, often in combination. The range of stimulus material is illustrated by the three units included in this chapter. *GREENHOUSE* has an extensive stimulus comprised of half a page of text and two graphs, whereas the stimulus of *PHYSICAL EXERCISE* is atypical in its brevity and reliance on visual suggestion.

■ Figure 3.9 ■

A tool for constructing and analysing assessment units and items

Context
Stimulus material
(*See Figure 3.2*)

→

Competencies
- Identifying scientific issues
- Explaining phenomena scientifically by applying scientific knowledge
- Using scientific evidence to make and communicate decisions
(*See Figure 3.6*)

←

Knowledge
- Knowledge *of* science (*basic concepts*) (*See Figure 3.7*)
- Knowledge *about* science (*See Figure 3.8*)

The reason PISA employs this unit structure is to facilitate the use of contexts that are as relevant as possible, and that reflect the complexity of real situations, while making efficient use of testing time. Using situations about which several questions can be posed, rather than asking separate questions about a larger number of different situations, reduces the overall time required for a student to become familiar with the material relating to each question. However, the need to make each scored point independent of others within a unit needs to be taken into account. It is also necessary to recognise that, because this approach reduces the number of different assessment contexts, it is important to ensure that there is an adequate range of contexts so that bias due to the choice of contexts is minimised.

PISA 2012 science test units incorporate up to four cognitive items that assess students' scientific competencies. Each item involves the predominant use of the skills involved in one of the scientific competencies, and primarily requires *knowledge of science* or *knowledge about science*. In most cases, more than one competency and more than one knowledge category are assessed (by different items) in this way within a unit.

Four types of items are used to assess the competencies and scientific knowledge identified in the framework: simple multiple-choice items, closed constructed-response items, complex multiple-choice items, and open constructed-response items. About one-third of the items are simple multiple-choice items, like Question 2 of *ACID RAIN*, which require the selection of a single response from four options. Another third of the items either require closed constructed-responses, or are complex multiple-choice items. Questions 1 and 2 of *PHYSICAL EXERCISE*, which require students to respond to a series of related "Yes/No" questions, are typical complex multiple-choice items. The remaining third of the items are open constructed-response items, like the remaining questions in *ACID RAIN* and *PHYSICAL EXERCISE* and the three items in *GREENHOUSE*. These require a relatively extended written or drawn response from students.

While the majority of items are dichotomously scored (that is, responses are either given all credit or no credit), some of the open constructed-response items allow for partial credit, and give students credit for having a partially correct answer. The categories "Full credit", "Partial credit" and "No credit" divide students' responses into three groups in terms of the extent to which the students demonstrate the ability to answer a question. A "Full credit" response requires a student to show a level of understanding of the topic that is appropriate for a scientifically literate 15-year-old student. Less sophisticated or correct responses may qualify for "Partial credit", with completely incorrect, irrelevant or missing responses being assigned "No credit". Question 3 of *ACID RAIN* and Question 2 of *GREENHOUSE* are partial credit items.

The need for students to possess a degree of reading literacy in order to understand and answer written questions on science raises an issue of the level of reading literacy required. Stimulus material and questions use language that is as clear, simple and brief as possible, while still conveying the appropriate meaning. The number of concepts introduced per paragraph is limited and questions that require too high a level of reading, or mathematics, are avoided.

Science assessment structure

Each PISA assessment must include an appropriate balance of items assessing scientific knowledge and competencies. Table 3.1 shows the distribution of score points among the *knowledge of science* and *knowledge about science* categories, expressed as percentages of the total score points, for both PISA 2006 (when science was the major domain) and PISA 2012.

Table 3.1
Approximate distribution of score points in science, by knowledge

	Percentage of score points	
Knowledge *of* science	**PISA 2006**	**PISA 2012**
Physical systems	17	13
Living systems	20	16
Earth and space systems	10	12
Technological systems	8	9
Subtotal	55	50
Knowledge *about* science		
Scientific enquiry	23	23
Scientific explanations	22	27
Subtotal	45	50
Total	**100**	**100**

The corresponding distributions for the scientific competencies are given in Table 3.2

Table 3.2
Approximate distribution of score points in science, by scientific competencies

	Percentage of score points	
Scientific competencies	**PISA 2006**	**PISA 2012**
Identifying scientific issues	22	23
Explaining phenomena scientifically	46	41
Using scientific evidence	32	37
Total	**100**	**100**

Item contexts are spread across *personal*, *social* and *global* settings approximately in the ratio 1:2:1, and there is a roughly even selection of areas of application as listed in Figure 3.2.

The distributions for item types are given in Table 3.3.

Table 3.3
Approximate distribution of score points in science, by item types

	Percentage of score points	
Item types	**PISA 2006**	**PISA 2012**
Simple multiple-choice	35	32
Complex multiple-choice	27	34
Closed constructed-response	4	2
Open constructed-response	34	32
Total	**100**	**100**

REPORTING PROFICIENCY IN SCIENCE

PISA results are reported on a scale constructed using a generalised form of the Rasch model as described by Adams, Wilson and Wang (1997). For each domain (reading, mathematics and science), a scale is constructed with a mean score of 500 and standard deviation of 100 among OECD countries; accordingly, about two-thirds of students across OECD countries score between 400 and 600 points.

When science was the major assessment domain for the first time in 2006, six proficiency levels were defined on the science scale. These same proficiency levels will be used in the reporting of science results for PISA 2012. Proficiency at each of the six levels can be understood in relation to the kinds of scientific competencies that a student needs to attain at each level. Figure 3.10 presents a description of the scientific knowledge and skills which students possess at the various proficiency levels, with Level 6 being the highest level of proficiency. It also gives the level and scale score of each item belonging to the three units from the PISA 2006 assessment, which are used as examples throughout this chapter.

The capacity of students who performed below Level 1 in PISA 2006 (about 5.2% of students on average across OECD countries) could not be reliably described because not enough science items were located in this region of the scale. Level 2 was established as the baseline level of scientific literacy, defining the level of achievement on the PISA scale at which students begin to demonstrate the scientific knowledge and skills that will enable them to participate actively in life situations related to science and technology.

■ Figure 3.10 ■

Summary descriptions of the six proficiency levels in science

Level	Lower score limit	Examples of items at each level	What students can typically do at each level
6	707.9	ACID RAIN Q3 Full credit (717) GREENHOUSE Q3 (709)	At Level 6, students can consistently identify, explain and apply scientific knowledge and knowledge about science in a variety of complex life situations. They can link different information sources and explanations and use evidence from those sources to justify decisions. They clearly and consistently demonstrate advanced scientific thinking and reasoning, and they use their scientific understanding in support of solutions to unfamiliar scientific and technological situations. Students at this level can use scientific knowledge and develop arguments in support of recommendations and decisions that centre on personal, social or global situations.
5	633.3	GREENHOUSE Q2 Full credit (659)	At Level 5, students can identify the scientific components of many complex life situations, apply both scientific concepts and knowledge about science to these situations, and can compare, select and evaluate appropriate scientific evidence for responding to life situations. Students at this level can use well-developed inquiry abilities, link knowledge appropriately and bring critical insights to situations. They can construct explanations based on evidence and arguments based on their critical analysis.
4	558.7	PHYSICAL EXERCISE Q3 (583) GREENHOUSE Q2 Partial credit (568)	At Level 4, students can work effectively with situations and issues that may involve explicit phenomena requiring them to make inferences about the role of science or technology. They can select and integrate explanations from different disciplines of science or technology and link those explanations directly to aspects of life situations. Students at this level can reflect on their actions and they can communicate decisions using scientific knowledge and evidence.
3	484.1	PHYSICAL EXERCISE Q1 (545) GREENHOUSE Q1 (529) ACID RAIN Q3 Partial credit (513) ACID RAIN Q1 (506)	At Level 3, students can identify clearly described scientific issues in a range of contexts. They can select facts and knowledge to explain phenomena and apply simple models or inquiry strategies. Students at this level can interpret and use scientific concepts from different disciplines and can apply them directly. They can develop short statements using facts and make decisions based on scientific knowledge.
2	409.5	ACID RAIN Q2 (460)	At Level 2, students have adequate scientific knowledge to provide possible explanations in familiar contexts or draw conclusions based on simple investigations. They are capable of direct reasoning and making literal interpretations of the results of scientific inquiry or technological problem solving.
1	334.9	PHYSICAL EXERCISE Q2 (386)	At Level 1, students have such a limited scientific knowledge that it can only be applied to a few, familiar situations. They can present scientific explanations that are obvious and follow explicitly from given evidence.

Factors that determine difficulty of items assessing science achievement include:

- The general complexity of the context.
- The level of familiarity of the scientific ideas, processes and terminology involved.
- The length of the train of logic required to respond to a question – that is, the number of steps needed to arrive at an adequate response and the level of dependence of each step on the previous one.
- The degree to which abstract scientific ideas or concepts are required in forming a response.
- The level of reasoning, insight and generalisation involved in forming judgements, conclusions and explanations.

Question 3 of *GREENHOUSE* is an example of a difficult item, located at Level 6 on the PISA science scale. This question combines aspects of the two competencies, *identifying scientific issues* and *explaining phenomena scientifically*. As a first step to solving this problem, the student must be able to identify the change and measured variables and have sufficient understanding of the methods of investigation to recognise the influence of other factors. In addition, the student needs to recognise the scenario and identify its major components. This involves identifying a number of abstract concepts and their relationships in order to determine what "other" factors might affect the relationship between Earth's temperature and the amount of carbon dioxide emissions in the atmosphere. Thus, in order to respond correctly, a student must understand the need to control factors outside the changed and measured variables and must possess sufficient knowledge of "Earth systems" to identify at least one of the factors that should be controlled. Sufficient knowledge of "Earth systems" is considered the critical scientific skill involved, so this question is categorised as *explaining phenomena scientifically*.

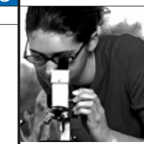
Question 1 of *PHYSICAL EXERCISE* is an example of an easy item, located at Level 1 on the PISA science scale below the baseline of scientific literacy. To gain credit, a student must correctly recall knowledge about the operation of muscles and formation of fat in the body, particularly the facts that when muscles are exercised they get an increased flow of blood and fats are not formed. This knowledge enables the student to accept the first statement of this complex multiple-choice question and reject the second one. In this item, no context needs to be analysed – the knowledge required has widespread currency and no relationships need investigating or establishing.

PISA 2006 results were also reported on three subscales corresponding to the three scientific competencies. These subscales used the same six proficiency levels as the combined scale, but with descriptors unique to each scale. In addition, country performance was compared on the bases of *knowledge about science* and the three main *knowledge of science* categories ("Physical systems", "Living systems", and "Earth and space systems").

While the analyses drawn from these kinds of comparisons could be valuable, caution should be used when relating performance to competencies and knowledge because the data come from classifying the same items in two ways that are not independent. All items classified as assessing the *identifying scientific issues* competency are *knowledge about science* items, and all *explaining phenomena scientifically* items are *knowledge of science* items (OECD, 2009, p. 44).

SUMMARY

The PISA definition of scientific literacy originates in the consideration of what 15-year-old students should know, value and be able to do as preparation for life in modern society. Central to the definition, and the science assessment, are the competencies that are characteristic of science and scientific enquiry: *identifying scientific issues, explaining phenomena scientifically,* and *using scientific evidence*. The ability of students to perform these competencies depends on their scientific knowledge, both knowledge of the natural world (i.e. knowledge of, chemistry, biology, Earth and space sciences, and technology) and *knowledge about science* itself (i.e. knowledge about "scientific enquiry" and "scientific explanations"), and their attitudes towards science-related issues.



This framework describes and illustrates the scientific competencies, knowledge and attitudes involved in the PISA definition of scientific literacy (see Figure 3.11), and outlines the format and structure of the PISA 2012 science assessment.

■ Figure 3.11 ■

Major components of the PISA definition of scientific literacy

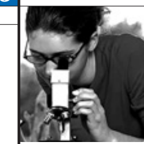
Competencies	**Knowledge**	**Attitudes**
■ Identifying scientific issues ■ Explaining scientific phenomena ■ Using scientific evidence	■ Knowledge *of* science: – *Physical systems* – *Living systems* – *Earth and space systems* – *Technology systems* ■ Knowledge *about* science – *Scientific enquiry* – *Scientific explanations*	■ Interest in science ■ Support for scientific enquiry ■ Responsibility towards resources and environment

PISA science test items are grouped into units with each unit beginning with stimulus material that establishes the context for its items. The focus is on situations in which applications of science have particular value in improving the quality of life of individuals and communities. A combination of multiple-choice and constructed-response item types is used and some items involve partial credit scoring. Unlike PISA 2006, attitudinal items are not included in units in PISA 2012.

PISA 2012 science results will be reported on a single science scale having a mean of 500 and a standard deviation of 100, using the six levels of proficiency defined when science was the major assessment domain for the first time in 2006. Level 6 is the highest level of proficiency and Level 2 has been established as the baseline level of scientific literacy. Students achieving below Level 2 do not demonstrate the scientific knowledge and skills that will enable them to participate actively in life situations related to science and technology.

Notes

1. Throughout this framework, "natural world" includes the changes made by human activity, including the "material world" designed and shaped by technologies.



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