2

PISA 2015 science framework

Science is the main subject of assessment in the Programme for International Student Assessment (PISA) in 2015. This chapter defines "scientific literacy" as assessed in PISA. It describes the types of contexts, knowledge, competencies and attitudes towards science that are reflected in the assessment's science problems and provides several sample items. The chapter also discusses how student performance in science is measured and reported.

This document provides a description of and rationale for the framework that forms the basis of the instrument to assess scientific literacy – the major domain in PISA 2015. Previous PISA frameworks for the science assessment (OECD, 2006, 2004, 1999) have elaborated a conception of scientific literacy as the central construct for science assessment. These documents have established a broad consensus among science educators of the concept of scientific literacy. This framework for PISA 2015 refines and extends the previous construct, in particular by drawing on the PISA 2006 framework that was used as the basis for assessment in 2006, 2009 and 2012.

Scientific literacy matters at both the national and international levels as humanity faces major challenges in providing sufficient water and food, controlling diseases, generating sufficient energy and adapting to climate change (UNEP, 2012). Many of these issues arise, however, at the local level where individuals may be faced with decisions about practices that affect their own health and food supplies, the appropriate use of materials and new technologies, and decisions about energy use. Dealing with all of these challenges will require a major contribution from science and technology. Yet, as argued by the European Commission, the solutions to political and ethical dilemmas involving science and technology "cannot be the subject of informed debate unless young people possess certain scientific awareness" (European Commission, 1995: 28). Moreover, "this does not mean turning everyone into a scientific expert, but enabling them to fulfil an enlightened role in making choices which affect their environment and to understand in broad terms the social implications of debates between experts" (ibid.: 28). Given that knowledge of science and science-based technology contributes significantly to individuals' personal, social, and professional lives, an understanding of science and technology is thus central to a young person's "preparedness for life".

The concept of scientific literacy in this framework *refers to a knowledge of both science and science-based technology*, even though science and technology do differ in their purposes, processes and products. Technology seeks the optimal solution to a human problem, and there may be more than one optimal solution. In contrast, science seeks the answer to a specific question about the natural, material world. Nevertheless, the two are closely related. For instance, new scientific knowledge leads to the development of new technologies (think of the advances in material science that led to the development of the transistor in 1948). Likewise, new technologies can lead to new scientific knowledge (think of how knowledge of the universe has been transformed through the development of better telescopes). Individuals make decisions and choices that influence the directions of new technologies (consider the decision to drive a smaller, more fuel-efficient car). Scientifically literate individuals should therefore be able to make more informed choices. They should also be able to recognise that, while science and technology are often a source of solutions, paradoxically, they can also be seen as a source of risk, generating new problems that can only be solved through the use of science and technology. Therefore, individuals need to be able to weigh the potential benefits and risks of applying scientific knowledge to themselves and society.

Scientific literacy also requires not just knowledge of the concepts and theories of science but also knowledge of the common procedures and practices associated with scientific enquiry and how these enable science to advance. Therefore, individuals who are scientifically literate have a knowledge of the major concepts and ideas that form the foundation of scientific and technological thought; how such knowledge has been derived; and the degree to which such knowledge is proved by evidence or theoretical explanations.

Undoubtedly, many of the challenges of the 21st century will require innovative solutions that have a basis in scientific thinking and scientific discovery. Societies will require a cadre of well-educated scientists to undertake the research and nurture the innovation that will be essential to meet the economic, social and environmental challenges that the world faces.

For all of these reasons, scientific literacy is perceived to be a key competency (Rychen and Salganik, 2003) and defined in terms of the ability to use knowledge and information interactively – that is "an understanding of how it [a knowledge of science] changes the way one can interact with the world and how it can be used to accomplish broader goals" (ibid.: 10). As such, it represents a major goal for science education for all students. Therefore, the view of scientific literacy that forms the basis for the 2015 international assessment of 15-year-old students is a response to the question: What is important for young people to know, value and be able to do in situations involving science and technology?

DEFINING SCIENTIFIC LITERACY

Current thinking about the desired outcomes of science education is rooted strongly in a belief that an understanding of science is so important that it should be a feature of every young person's education (American Association for the Advancement of Science, 1989; Confederacion de Sociedades Cientificas de España, 2011; Fensham, 1985; Millar and Osborne, 1998; National Research Council, 2012; Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland [KMK], 2005; Taiwan Ministry of Education, 1999). Indeed, in many countries science is an obligatory element of the school curriculum from kindergarten until the completion of compulsory education.

Many of the documents and policy statements cited above give pre-eminence to an education for citizenship. However, many of the curricula for school science across the world are based on a view that the primary goal of science education should be the preparation of the next generation of scientists (Millar and Osborne, 1998). These two goals are not always compatible. Attempts to resolve the tension between the needs of the majority of students who will not become scientists and the needs of the minority who will have led to an emphasis on teaching science through enquiry (National Academy of Science, 1995; National Research Council, 2000), and new curriculum models (Millar, 2006) that address the needs of both groups. The emphasis in these frameworks and their associated curricula lies not on producing individuals who will be "producers" of scientific knowledge, i.e. the future scientists; rather, it is on educating all young people to become informed, critical users of scientific knowledge.

To understand and engage in critical discussions about issues that involve science and technology requires three domain-specific competencies. The first is the ability to provide explanatory accounts of natural phenomena, technical artefacts and technologies, and their implications for society. Such an ability requires a knowledge of the fundamental ideas of science and the questions that frame the practice and goals of science. The second is the knowledge and understanding of scientific enquiry to: identify questions that can be answered by scientific enquiry; identify whether appropriate procedures have been used; and propose ways in which such questions might be answered. The third is the competency to interpret and evaluate data and evidence scientifically and evaluate whether the conclusions are justified. Thus, scientific literacy in PISA 2015 is defined by the three competencies to:

- explain phenomena scientifically
- evaluate and design scientific enquiry
- interpret data and evidence scientifically.

All of these competencies require knowledge. Explaining scientific and technological phenomena, for instance, demands a knowledge of the content of science (hereafter, content knowledge). The second and third competencies, however, require more than a knowledge of what is known; they depend on an understanding of how scientific knowledge is established and the degree of confidence with which it is held. Some have argued for teaching what has variously been called "the nature of science" (Lederman, 2006), "ideas about science" (Millar and Osborne, 1998) or "scientific practices" (National Research Council, 2012). Recognising and identifying the features that characterise scientific enquiry requires a knowledge of the standard procedures that underlie the diverse methods and practices used to establish scientific knowledge (hereafter, procedural knowledge). Finally, the competencies require epistemic knowledge – an understanding of the rationale for the common practices of scientific enquiry, the status of the knowledge claims that are generated, and the meaning of foundational terms, such as theory, hypothesis and data.

Box 2.1 Scientific knowledge: PISA 2015 terminology

This document is based upon a view of scientific knowledge as consisting of three distinguishable but related elements. The first of these and the most familiar is a knowledge of the facts, concepts, ideas and theories about the natural world that science has established. For instance, how plants synthesise complex molecules using light and carbon dioxide or the particulate nature of matter. This kind of knowledge is referred to as "**content knowledge**" or "knowledge of the content of science".

Knowledge of the procedures that scientists use to establish scientific knowledge is referred to as "**procedural knowledge**". This is a knowledge of the practices and concepts on which empirical enquiry is based such as repeating measurements to minimise error and reduce uncertainty, the control of variables, and standard procedures for representing and communicating data (Millar, Lubben, Gott and Duggan, 1995). More recently these have been elaborated as a set of "concepts of evidence" (Gott, Duggan and Roberts, 2008).

Furthermore, understanding science as a practice also requires "**epistemic knowledge**" which refers to an understanding of the role of specific constructs and defining features essential to the process of knowledge-building in science (Duschl, 2007). Epistemic knowledge includes an understanding of the function that questions, observations, theories, hypotheses, models and arguments play in science; a recognition of the variety of forms of scientific enquiry; and the role peer review plays in establishing knowledge that can be trusted.

A more detailed discussion of these three forms of knowledge is provided in the later section on scientific knowledge and in Figures 2.5, 2.6 and 2.7.

Both procedural and epistemic knowledge are necessary to identify questions that are amenable to scientific enquiry, to judge whether appropriate procedures have been used to ensure that the claims are justified, and to distinguish scientific issues from matters of values or economic considerations. This definition of scientific literacy assumes that, throughout their lives, individuals will need to acquire knowledge, not through scientific investigations, but through the use of resources such as libraries and the Internet. Procedural and epistemic knowledge are essential to decide whether the many claims of knowledge and understanding that pervade contemporary media are based on the use of appropriate procedures and are justified.

People need all three forms of scientific knowledge to perform the three competencies of scientific literacy. PISA 2015 focuses on assessing the extent to which 15-year-olds are capable of displaying the three aforementioned competencies appropriately within in a range of personal, local/national (grouped in one category) and global contexts. (For the purposes of the PISA assessment, these competencies are only tested using the knowledge that 15-year-old students can reasonably be expected to have already acquired.) This perspective differs from that of many school science programmes that are dominated by content knowledge. Instead, the framework is based on a broader view of the kind of knowledge of science required of fully engaged citizens.

In addition, the competency-based perspective also recognises that there is an affective element to a student's display of these competencies: students' attitudes or disposition towards science will determine their level of interest, sustain their engagement, and may motivate them to take action (Schibeci, 1984). Thus, the scientifically literate person would typically have an interest in scientific topics; engage with science-related issues; have a concern for issues of technology, resources and the environment; and reflect on the importance of science from a personal and social perspective. This requirement does not mean that such individuals are necessarily disposed towards becoming scientists themselves, rather such individuals recognise that science, technology and research in this domain are an essential element of contemporary culture that frames much of our thinking.

These considerations led to the definition of scientific literacy used in PISA 2015 (see Box 2.2). The use of 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 real-life situations.

Box 2.2 **The 2015 definition of scientific literacy**

Scientific literacy is the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen.

A scientifically literate person is willing to engage in reasoned discourse about science and technology, which requires the competencies to:

- **Explain phenomena scientifically** – recognise, offer and evaluate explanations for a range of natural and technological phenomena.

- **Evaluate and design scientific enquiry** – describe and appraise scientific investigations and propose ways of addressing questions scientifically.

- **Interpret data and evidence scientifically** – analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions.

The competencies required for scientific literacy

Competency 1: Explain phenomena scientifically

The cultural achievement of science has been to develop a set of explanatory theories that have transformed our understanding of the natural world (in this document, "natural world" refers to phenomena associated with any object or activity occurring in the living or material world), such as the idea that day and night is caused by a rotating Earth, or the idea that diseases can be caused by invisible micro-organisms. Moreover, such knowledge has enabled us to develop technologies that support human life by, for example, preventing disease or enabling rapid human communication across the globe. The competency to explain scientific and technological phenomena is thus dependent on a knowledge of these major explanatory ideas of science.

Explaining scientific phenomena, however, requires more than the ability to recall and use theories, explanatory ideas, information and facts (content knowledge). Offering scientific explanations also requires an understanding of how such knowledge has been derived and the level of confidence we might hold about any scientific claims. For this competency, the individual requires a knowledge of the standard forms and procedures used in scientific enquiry to obtain such knowledge (procedural knowledge) and an understanding of their role and function in justifying the knowledge produced by science (epistemic knowledge).

Competency 2: Evaluate and design scientific enquiry

Scientific literacy implies that students have some understanding of the goal of scientific enquiry, which is to generate reliable knowledge about the natural world (Ziman, 1979). Data collected and obtained by observation and experiment, either in the laboratory or in the field, lead to the development of models and explanatory hypotheses that enable predictions that can then be tested experimentally. New ideas, however, commonly build on previous knowledge. Scientists themselves rarely work in isolation; they are members of research groups or teams that engage, nationally and internationally, in extensive collaboration with colleagues. New knowledge claims are always perceived to be provisional and may lack justification when subjected to critical peer review – the mechanism through which the scientific community ensures the objectivity of scientific knowledge (Longino, 1990). Hence, scientists have a commitment to publish or report their findings and the methods used in obtaining their evidence. Doing so enables empirical studies, at least in principle, to be replicated and results confirmed or challenged. However, measurements can never be absolutely precise; they all contain a degree of error. Much of the work of the experimental scientist is thus devoted to resolving uncertainty by repeating measurements, collecting larger samples, building instruments that are more accurate and using statistical techniques that assess the degree of confidence in any result.

In addition, science has well-established procedures that are the foundations of any experiment to establish cause and effect. The use of controls enables the scientist to claim that any change in a perceived outcome can be attributed to a change in one specific feature. Failure to use such techniques leads to results where effects are confounded and cannot be trusted. Likewise, double-blind trials enable scientists to claim that the results have not been influenced either by the subjects of the experiment, or by the experimenter themselves. Other scientists, such as taxonomists and ecologists, are engaged in the process of identifying underlying patterns and interactions in the natural world that warrant a search for an explanation. In other cases, such as evolution, plate tectonics or climate change, scientists examine a range of hypotheses and eliminate those that do not fit with the evidence.

Facility with this competency draws on content knowledge, a knowledge of the common procedures used in science (procedural knowledge), and the function of these procedures in justifying any claims advanced by science (epistemic knowledge). Procedural and epistemic knowledge serve two functions. First, such knowledge is required by individuals to appraise scientific investigations and decide whether they have followed appropriate procedures and whether the conclusions are justified. Second, individuals who have this knowledge should be able to propose, at least in broad terms, how a scientific question might be investigated appropriately.

Competency 3: Interpret data and evidence scientifically

Interpreting data is such a core activity of all scientists that some rudimentary understanding of the process is essential for scientific literacy. Initially, data interpretation begins with looking for patterns, constructing simple tables and graphical visualisations, such as pie charts, bar graphs, scatterplots or Venn diagrams. At a higher level, it requires the use of more complex data sets and the use of the analytical tools offered by spreadsheets and statistical packages. It would be wrong, however, to look at this competency as merely an ability to use these tools. A substantial body of knowledge is required to recognise what constitutes reliable and valid evidence and how to present data appropriately.

Scientists make choices about how to represent the data in graphs, charts or, increasingly, in complex simulations or 3D visualisations. Any relationships or patterns must then be read using a knowledge of standard patterns. Whether uncertainty has been minimised by standard statistical techniques must also be considered. All of this draws on a body of procedural knowledge. The scientifically literate individual can also be expected to understand that uncertainty is an inherent feature of all measurement, and that one criterion for expressing confidence in a finding is determining the probability that the finding might have occurred by chance.

It is not sufficient, however, to understand the procedures that have been applied to obtain any data set. The scientifically literate individual needs to be able to judge whether they are appropriate and the ensuing claims are justified (epistemic knowledge). For instance, many sets of data can be interpreted in multiple ways. Argumentation and critique are essential to determining which is the most appropriate conclusion.

Whether it is new theories, novel ways of collecting data or fresh interpretations of old data, argumentation is the means that scientists and technologists use to make their case for new ideas. Disagreement among scientists is normal, not extraordinary. Determining which interpretation is the best requires a knowledge of science (content knowledge). Consensus on key scientific ideas and concepts has been achieved through this process of critique and argumentation (Longino, 1990). Indeed, it is a critical and sceptical disposition towards all empirical evidence that many would see as the hallmark of the professional scientist. The scientifically literate individual understands the function and purpose of argument and critique and why they are essential to the construction of knowledge in science. In addition, they should be able both to construct claims that are justified by data and to identify any flaws in the arguments of others.

The evolution of the definition of scientific literacy in PISA

In PISA 2000 and 2003, scientific literacy was defined as:

> "…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." (OECD, 2004, 2000)

In 2000 and 2003, the definition embedded knowledge *of* science and understandings *about* science within the one term "scientific knowledge". The 2006 definition separated and elaborated the term "scientific knowledge" by dividing it into two components: "knowledge *of* science" and "knowledge *about* science" (OECD, 2006). Both definitions referred to the application of scientific knowledge to understanding and making informed decisions about the natural world. In PISA 2006, the definition was enhanced by the addition of knowledge of the relationship between science and technology – an aspect that was assumed but not elaborated in the 2003 definition.

> "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." (OECD, 2006).

These ideas have evolved further in the PISA 2015 definition of scientific literacy. The major difference is that the notion of "knowledge *about* science" has been specified more clearly and split into two components – procedural knowledge and epistemic knowledge.

In 2006, the PISA framework was also expanded to include attitudinal aspects of students' responses to scientific and technological issues within the construct of scientific literacy. In 2006, attitudes were measured in two ways: through the student questionnaire and through items embedded in the student test. Discrepancies were found between the results from the embedded questions and those from the background questionnaire with respect to "interest in science" for all students and gender differences in these issues (OECD, 2009; see also Drechsel, Carstensen and Prenzel, 2011). More important, embedded items extended the length of the test. Hence, in PISA 2015, attitudinal aspects are only measured through the student questionnaire; there are no embedded attitudinal items.

As for the constructs measured within this domain, the first ("interest in science") and third ("environmental awareness") remain the same as in 2006. The second ("support for scientific enquiry") has been changed to a measure of "valuing scientific approaches to enquiry", which is essentially a change in terminology to better reflect what is measured.

In addition, the contexts in PISA 2015 have been changed from "personal, social and global" in the 2006 assessment to "personal, local/national and global" to make the headings more coherent.

ORGANISING THE DOMAIN OF SCIENCE

The PISA 2015 definition of scientific literacy consists of four interrelated aspects (see Figures 2.1 and 2.2).

Figure 2.1 ▪ **Aspects of the scientific literacy assessment framework for PISA 2015**

Contexts	Personal, local/national and global issues, both current and historical, which demand some understanding of science and technology.
Knowledge	An understanding of the major facts, concepts and explanatory theories that form the basis of scientific knowledge. Such knowledge includes knowledge of both the natural world and technological artefacts (content knowledge), knowledge of how such ideas are produced (procedural knowledge), and an understanding of the underlying rationale for these procedures and the justification for their use (epistemic knowledge).
Competencies	The ability to explain phenomena scientifically, evaluate and design scientific enquiry, and interpret data and evidence scientifically.
Attitudes	A set of attitudes towards science indicated by an interest in science and technology, valuing scientific approaches to enquiry where appropriate, and a perception and awareness of environmental issues.

Figure 2.2 ▪ **Inter-relations between the four aspects**
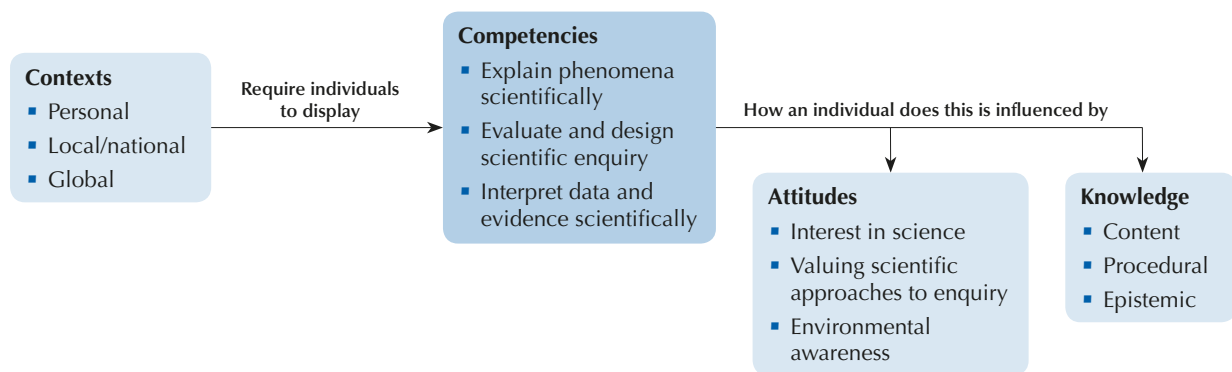
Contexts of assessment items

PISA 2015 assesses scientific knowledge in contexts that are relevant to the science curricula of participating countries. Such contexts are not, however, restricted to the common aspects of participants' national curricula. Rather, the assessment requires evidence of the successful use of the three competencies required for scientific literacy in situations set in personal, local/national and global contexts.

Assessment items are not limited to school science contexts. In the PISA 2015 scientific literacy assessment, the items focus on situations relating to the self, family and peer groups (personal), to the community (local and national), and to life across the world (global). Technology-based topics may be used as a common context. Some topics may be set in historical contexts, which are used to assess students' understanding of the processes and practices involved in advancing scientific knowledge.

Figure 2.3 shows how science and technology issues are applied within personal, local/national and global settings. The contexts are chosen in light of their relevance to students' interests and lives. The areas of application are: health and disease, natural resources, environmental quality, hazards, and the frontiers of science and technology. They are the areas in which scientific literacy has particular value for individuals and communities in enhancing and sustaining quality of life, and in developing public policy.

The PISA science assessment is *not* an assessment of contexts. Rather, it assesses competencies and knowledge *in* specific contexts. These contexts are chosen on the basis of the knowledge and understanding that students are likely to have acquired by the age of 15.

Sensitivity to linguistic and cultural differences is a priority in item development and selection, not only for the sake of the validity of the assessment, but also to respect these differences among participating countries.

Figure 2.3 ▪ **Contexts in the PISA 2015 scientific literacy assessment**

	Personal	Local/National	Global
Health and disease	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 natural systems, population growth, sustainable use of species
Environmental quality	Environmentally friendly actions, use and disposal of materials and devices	Population distribution, disposal of waste, environmental impact	Biodiversity, ecological sustainability, control of pollution, production and loss of soil/biomass
Hazards	Risk assessments of lifestyle choices	Rapid changes (e.g. earthquakes, severe weather), slow and progressive changes (e.g. coastal erosion, sedimentation), risk assessment	Climate change, impact of modern communication
Frontiers of science and technology	Scientific aspects of hobbies, personal technology, music and sporting activities	New materials, devices and processes, genetic modifications, health technology, transport	Extinction of species, exploration of space, origin and structure of the universe

Scientific competencies

Figures 2.4a, 2.4b and 2.4c provide a detailed description of how students may display the three competencies required for scientific literacy. The set of scientific competencies in Figures 2.4a, 2.4b and 2.4c reflects a view that science is best seen as an ensemble of social and epistemic practices that are common across all sciences (National Research Council, 2012). Hence, all these competencies are framed as actions. They are written in this manner to convey the idea of what the scientifically literate person both understands and is capable of doing. Fluency with these practices is, in part, what distinguishes the expert scientist from the novice. While it would be unreasonable to expect a 15-year-old student to have the expertise of a scientist, a scientifically literate student can be expected to appreciate the role and significance of these practices and try to use them.

Figure 2.4a ▪ **PISA 2015 scientific competencies: Explain phenomena scientifically**

Explain phenomena scientifically

Recognise, offer and evaluate explanations for a range of natural and technological phenomena demonstrating the ability to:
- Recall and apply appropriate scientific knowledge.
- Identify, use and generate explanatory models and representations.
- Make and justify appropriate predictions.
- Offer explanatory hypotheses.
- Explain the potential implications of scientific knowledge for society.

Demonstrating the competency of *explaining phenomena scientifically* requires students to recall the appropriate content knowledge in a given situation and use it to interpret and explain the phenomenon of interest. Such knowledge can also be used to generate tentative explanatory hypotheses in contexts where there is a lack of knowledge or data. A scientifically literate person is expected to be able to draw on standard scientific models to construct simple representations to explain everyday phenomena, such as why antibiotics do not kill viruses, how a microwave oven works, or why gases are compressible but liquids are not, and use these to make predictions. This competency includes the ability to describe or interpret phenomena and predict possible changes. In addition, it may involve recognising or identifying appropriate descriptions, explanations and predictions.

Figure 2.4b ■ **PISA 2015 scientific competencies : Evaluate and design scientific enquiry**

Evaluate and design scientific enquiry

Describe and appraise scientific investigations and propose ways of addressing questions scientifically demonstrating the ability to:

- Identify the question explored in a given scientific study.
- Distinguish questions that could be investigated scientifically.
- Propose a way of exploring a given question scientifically.
- Evaluate ways of exploring a given question scientifically.
- Describe and evaluate how scientists ensure the reliability of data, and the objectivity and generalisability of explanations.

The competency of *evaluating and designing scientific enquiry* is required to evaluate reports of scientific findings and investigations critically. It relies on the ability to distinguish scientific questions from other forms of enquiry or recognise questions that could be investigated scientifically in a given context. This competency requires a knowledge of the key features of a scientific investigation – for example, what things should be measured, what variables should be changed or controlled, or what action should be taken so that accurate and precise data can be collected. It requires an ability to evaluate the quality of data, which, in turn, depends on recognising that data are not always completely accurate. It also requires the ability to determine whether an investigation is driven by an underlying theoretical premise or, alternatively, whether it seeks to determine patterns.

A scientifically literate person should also be able to recognise the significance of previous research when judging the value of any given scientific enquiry. Such knowledge is needed to situate the work and judge the importance of any possible outcomes. For example, knowing that the search for a malaria vaccine has been an ongoing programme of scientific research for several decades, and given the number of people who are killed by malarial infections, any findings that suggested a vaccine would be achievable would be of substantial significance.

Moreover, students need to understand the importance of developing a sceptical attitude towards all media reports in science. They need to recognise that all research builds on previous work, that the findings of any one study are always subject to uncertainty, and that the study may be biased by the sources of funding. This competency requires students to possess both procedural and epistemic knowledge but may also draw on their content knowledge of science, to varying degrees.

Figure 2.4c ■ **PISA 2015 scientific competencies: Interpret data and evidence scientifically**

Interpret data and evidence scientifically

Analyse and evaluate scientific data, claims and arguments in a variety of representations and draw appropriate conclusions, demonstrating the ability to:

- Transform data from one representation to another.
- Analyse and interpret data and draw appropriate conclusions.
- Identify the assumptions, evidence and reasoning in science-related texts.
- Distinguish between arguments that are based on scientific evidence and theory and those based on other considerations.
- Evaluate scientific arguments and evidence from different sources (e.g. newspapers, the Internet, journals).

A scientifically literate person should be able to interpret and make sense of basic forms of scientific data and evidence that are used to make claims and draw conclusions. Displaying this competency may require all three forms of scientific knowledge.

Those who possess this competency should be able to interpret the meaning of scientific evidence and its implications to a specified audience in their own words, using diagrams or other representations as appropriate. This competency requires the use of mathematical tools to analyse or summarise data, and the ability to use standard methods to transform data into different representations.

This competency also includes accessing scientific information and producing and evaluating arguments and conclusions based on scientific evidence (Kuhn, 2010; Osborne, 2010). It may also involve evaluating alternative conclusions using

evidence; giving reasons for or against a given conclusion using procedural or epistemic knowledge; and identifying the assumptions made in reaching a conclusion. In short, the scientifically literate individual should be able to identify logical or flawed connections between evidence and conclusions.

Table 2.1 shows the desired distribution of items, by competency, in the PISA 2015 science assessment.

Table 2.1 Desired distribution of items, by competency

Competency	Percentage of total items
Explain phenomena scientifically	40-50
Evaluate and design scientific enquiry	20-30
Interpret data and evidence scientifically	30-40

Scientific knowledge

Content knowledge

Given that only a sample of the content domain of science can be assessed in the PISA 2015 scientific literacy assessment, clear criteria are used to guide the selection of the knowledge that is assessed. The criteria are applied to knowledge from the major fields of physics, chemistry, biology, earth and space sciences, and require that the knowledge:

- has relevance to real-life situations
- represents an important scientific concept or major explanatory theory that has enduring utility
- is appropriate to the developmental level of 15-year-olds.

It is thus assumed that students have some knowledge and understanding of the major explanatory ideas and theories of science, including an understanding of the history and scale of the universe, the particle model of matter, and the theory of evolution by natural selection. These examples of major explanatory ideas are provided for illustrative purposes; there has been no attempt to list comprehensively all the ideas and theories that might be considered fundamental for a scientifically literate individual.

Figure 2.5 ▪ **Knowledge of the content of science**

Physical systems that require knowledge of:

- 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. chemical reactions, energy transfer, acids/bases)
- Motion and forces (e.g. velocity, friction) and action at a distance (e.g. magnetic, gravitational and electrostatic forces)
- Energy and its transformation (e.g. conservation, dissipation, chemical reactions)
- Interactions between energy and matter (e.g. light and radio waves, sound and seismic waves)

Living systems that require knowledge of:

- Cells (e.g. structures and function, DNA, plant and animal)
- The concept of an organism (e.g. unicellular and multicellular)
- Humans (e.g. health, nutrition, subsystems such as digestion, respiration, circulation, excretion, reproduction and their relationship)
- 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 that require knowledge of:

- Structures of the Earth systems (e.g. lithosphere, atmosphere, hydrosphere)
- Energy in the 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, galaxies)
- The history and scale of the universe and its history (e.g. light year, Big Bang theory)

Figure 2.5 shows the content knowledge categories and examples selected by applying these criteria. Such knowledge is required for understanding the natural world and for making sense of experiences in personal, local/national and global contexts. The framework uses the term "systems" instead of "sciences" in the descriptors of content knowledge. The intention is to convey the idea that citizens have to understand concepts from the physical and life sciences, and earth and space sciences, and how they apply in contexts where the elements of knowledge are interdependent or interdisciplinary. Things viewed as subsystems at one scale may be viewed as whole systems at a smaller scale. For example, the circulatory system can be seen as an entity in itself or as a subsystem of the human body; a molecule can be studied as a stable configuration of atoms but also as a subsystem of a cell or a gas. Thus, applying scientific knowledge and exhibiting scientific competencies requires a determination of which system and which boundaries apply in any particular context.

Table 2.2 shows the desired distribution of items, by content of science.

Table 2.2 Desired distribution of items, by content

System	Percentage of total items
Physical	36
Living	36
Earth and space	28
Total	100

Procedural knowledge

A fundamental goal of science is to generate explanatory accounts of the material world. Tentative explanatory accounts are first developed and then tested through empirical enquiry. Empirical enquiry relies on certain well-established concepts, such as the notion of dependent and independent variables, the control of variables, types of measurement, forms of error, methods of minimising error, common patterns observed in data, and methods of presenting data.

It is this knowledge of the concepts and procedures that are essential for scientific enquiry that underpins the collection, analysis and interpretation of scientific data. Such ideas form a body of procedural knowledge that has also been called "concepts of evidence" (Gott, Duggan and Roberts, 2008; Millar et al., 1995). One can think of procedural knowledge as knowledge of the standard procedures scientists use to obtain reliable and valid data. Such knowledge is needed both to undertake scientific enquiry and engage in critical reviews of the evidence that might be used to support particular claims. It is expected, for instance, that students will know that scientific knowledge has differing degrees of certainty associated with it, and so can explain why there is a difference between the confidence associated with measurements of the speed of light (which has been measured many times with ever more accurate instrumentation) and measurements of fish stocks in the North Atlantic or the mountain lion population in California. The examples listed in Figure 2.6 convey the general features of procedural knowledge that may be tested.

Figure 2.6 ■ **PISA 2015 procedural knowledge**

Procedural knowledge

- The concept of variables, including dependent, independent and control variables.
- Concepts of measurement, e.g. quantitative (measurements), qualitative (observations), the use of a scale, categorical and continuous variables.
- Ways of assessing and minimising uncertainty, such as repeating and averaging measurements.
- Mechanisms to ensure the replicability (closeness of agreement between repeated measures of the same quantity) and accuracy of data (the closeness of agreement between a measured quantity and a true value of the measure).
- Common ways of abstracting and representing data using tables, graphs and charts, and using them appropriately.
- The control-of-variables strategy and its role in experimental design or the use of randomised controlled trials to avoid confounded findings and identify possible causal mechanisms.
- The nature of an appropriate design for a given scientific question, e.g. experimental, field-based or pattern-seeking.

Epistemic knowledge

Epistemic knowledge refers to an understanding of the role of specific constructs and defining features essential to the process of knowledge building in science (Duschl, 2007). Those who have such knowledge can explain, with examples, the distinction between a scientific theory and a hypothesis or a scientific fact and an observation. They know that models, whether representational, abstract or mathematical, are a key feature of science, and that such models are

like maps rather than accurate pictures of the material world. These students can recognise that any particle model of matter is an idealised representation of matter and can explain how the Bohr model is a limited model of what we know about the atom and its constituent parts. They recognise that the concept of a "theory" as used in science is not the same as the notion of a "theory" in everyday language, where it is used as a synonym for a "guess" or a "hunch". Procedural knowledge is required to explain what is meant by the control-of-variables strategy; epistemic knowledge is required to explain *why* the use of the control-of-variables strategy or the replication of measurements is central to establishing knowledge in science.

Scientifically literate individuals also understand that scientists draw on data to advance claims to knowledge, and that argument is a commonplace feature of science. In particular, they know that some arguments in science are hypothetico-deductive (e.g. Copernicus' argument for the heliocentric system), some are inductive (the conservation of energy), and some are an inference to the best explanation (Darwin's theory of evolution or Wegener's argument for moving continents). They also understand the role and significance of peer review as the mechanism that the scientific community has established for testing claims to new knowledge. As such, epistemic knowledge provides a rationale for the procedures and practices in which scientists engage, a knowledge of the structures and defining features that guide scientific enquiry, and the foundation for the basis of belief in the claims that science makes about the natural world.

Figure 2.7 represents what are considered to be the major features of epistemic knowledge necessary for scientific literacy.

Figure 2.7 ▪ **PISA 2015 epistemic knowledge**

Epistemic knowledge

The constructs and defining features of science. That is:
- The nature of scientific observations, facts, hypotheses, models and theories.
- The purpose and goals of science (to produce explanations of the natural world) as distinguished from technology (to produce an optimal solution to human need), and what constitutes a scientific or technological question and appropriate data.
- The values of science, e.g. a commitment to publication, objectivity and the elimination of bias.
- The nature of reasoning used in science, e.g. deductive, inductive, inference to the best explanation (abductive), analogical, and model-based.

The role of these constructs and features in justifying the knowledge produced by science. That is:
- How scientific claims are supported by data and reasoning in science.
- The function of different forms of empirical enquiry in establishing knowledge, their goal (to test explanatory hypotheses or identify patterns) and their design (observation, controlled experiments, correlational studies).
- How measurement error affects the degree of confidence in scientific knowledge.
- The use and role of physical, system and abstract models and their limits.
- The role of collaboration and critique, and how peer review helps to establish confidence in scientific claims.
- The role of scientific knowledge, along with other forms of knowledge, in identifying and addressing societal and technological issues.

Epistemic knowledge is most likely to be tested pragmatically in a context where a student is required to interpret and answer a question that requires some of this type of knowledge rather than assessing directly whether they understand the features detailed in Figure 2.7. For example, students may be asked to identify whether the conclusions are justified by the data, or what piece of evidence best supports the hypothesis advanced in an item and explain why.

Table 2.3 describes the desired distribution of items by type of knowledge.

Table 2.3 **Desired distribution of items, by type of knowledge**

Knowledge	Percentage of total items
Content	54-66
Procedural	19-31
Epistemic	10-22

The desired balance, by percentage of items, among the three knowledge components – content, procedural and epistemic – is shown in Table 2.4. These weightings are broadly consistent with the previous framework and reflect a consensus view among the experts consulted during the drafting of this framework.

Table 2.4 Desired distribution of items for knowledge

Knowledge types	Systems			
	Physical	**Living**	**Earth and space**	**Total over systems**
Content	20-24	20-24	14-18	54-66
Procedural	7-11	7-11	5-9	19- 31
Epistemic	4-8	4-8	2-6	10-22
Total over knowledge types	36	36	28	100

Sample items

In this section, three examples of science units are presented. The first is from PISA 2006 and is included to demonstrate the linkage between the 2006 and the 2015 frameworks. Questions from the unit are shown in the original paper-based format and also how they might be transposed and presented on screen. The second example is a new onscreen unit illustrating the 2015 scientific literacy framework. The third example illustrates an interactive, simulated scientific-enquiry environment which allows for assessing students' proficiency in science within a real world setting.

Other examples of science items are available on the PISA website (www.oecd.org/pisa/), including interactive examples (November 2016).

Science example 1: GREENHOUSE

Science example 1 is entitled GREENHOUSE and deals with the increase in 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 carbon dioxide emissions on Earth over time.

The area of application is Environment Quality within a global setting.

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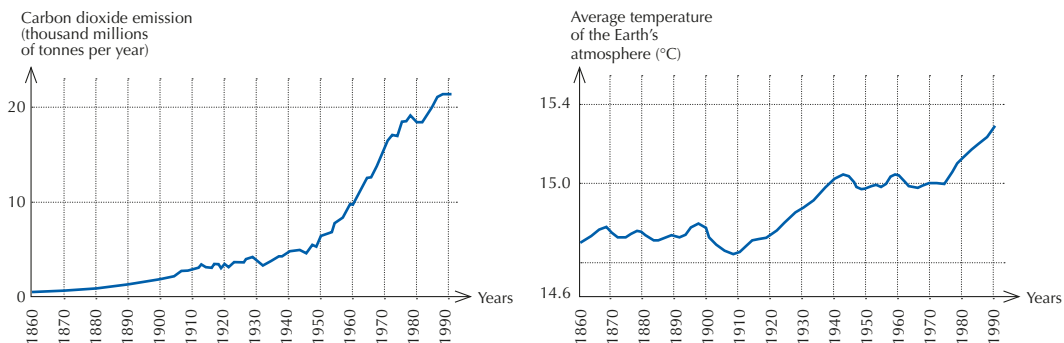
André concludes from these two graphs that it is certain that the increase in the average temperature of the Earth's atmosphere is due to the increase in the carbon dioxide emission.

GREENHOUSE – *QUESTION 1*

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

Figure 2.8 ■ **Framework categorisation for GREENHOUSE question 1**

Framework categories	2006 Framework	2015 Framework
Knowledge type	Knowledge about science	Epistemic
Competency	Explaining phenomena scientifically	Explaining phenomena scientifically
Context	Environmental, global	Environmental, global
Cognitive demand	Not applicable	Medium

Question 1 demonstrates how the 2015 framework largely maps onto the same categories as the 2006 framework, using the same competency and context categorisations. The 2006 framework included two categorisations of scientific knowledge: knowledge *of* science (referring to knowledge of the natural world across the major fields of science) and knowledge *about* science (referring to the means and goals of science). The 2015 framework elaborates on these two aspects, subdividing knowledge *about* science into procedural and epistemic knowledge. Question 1 requires students not only to understand how the data is represented in the two graphs, but also to consider whether this evidence scientifically justifies a given conclusion. This is one of the features of epistemic knowledge in the 2015 framework. The context categorisation is "environmental, global". A new feature of the 2015 framework is consideration of cognitive demand (see Figure 2.23). This question requires an interpretation of graphs involving a few linked steps; thus, according to the framework, it is categorised as medium cognitive demand.

GREENHOUSE – *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.

....

Figure 2.9 ■ **Framework categorisation for GREENHOUSE question 2**

Framework categories	2006 Framework	2015 Framework
Knowledge type	Knowledge about science	Epistemic
Competency	Explaining phenomena scientifically	Explaining phenomena scientifically
Context	Environmental, global	Environmental, global
Cognitive demand	Not applicable	Medium

Question 2 requires students to study the two graphs in detail. The knowledge, competency, context and cognitive demand are in the same categories as question 1.

GREENHOUSE – *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.

....

Figure 2.10 ■ **Framework categorisation for GREENHOUSE question 3**

Framework categories	2006 Framework	2015 Framework
Knowledge type	Knowledge about science	Procedural
Competency	Explaining phenomena scientifically	Explaining phenomena scientifically
Context	Environmental, global	Environmental, global
Cognitive demand	Not applicable	Medium

Question 3 requires students to consider control variables in terms of the critical review of evidence used to support claims. This is categorised as "procedural knowledge" in the 2015 framework.

The screenshots below illustrate how the GREENHOUSE question would be presented in an onscreen environment. The text and graphs are essentially unchanged, with students using page turners on the top right of the screen to view graphs and text as required. As the original questions were open responses, the onscreen version also necessitates an open-response format in order to replicate the paper version as closely as possible, ensuring comparability between delivery modes and therefore protecting comparability of data over time.

Figure 2.11 ▪ **GREENHOUSE presented onscreen: Stimulus page 1**

PISA 2015   ?   ⬅ ➡

2

Greenhouse effect
Introduction

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 periodicals the increased carbon dioxide emission is often stated as the main source of the temperature rise in the twentieth century.

Figure 2.12 ▪ **GREENHOUSE presented onscreen: Stimulus page 2**

PISA 2015   ?   ⬅ ➡

1   2

Greenhouse effect
Introduction

*Now click on **Next** to view the first question.*

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.

Carbon dioxide emission (thousand millions of tonnes per year) — 20, 10, 0 — Years: 1860, 1870, 1880, 1890, 1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970, 1980, 1990

Average temperature of the Earth's atmosphere (°C) — 15.4, 15.0, 14.6 — Years: 1860, 1870, 1880, 1890, 1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970, 1980, 1990

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.

Figure 2.13 ▪ **GREENHOUSE presented onscreen: Question 1**

PISA 2015   ? ⬅ ➡

2

Greenhouse effect
Question 1/3

Type your answer to the question below.

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

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 periodicals the increased carbon dioxide emission is often stated as the main source of the temperature rise in the twentieth century.

Figure 2.14 ▪ **GREENHOUSE presented onscreen: Question 2**

PISA 2015   ? ⬅ ➡

2

Greenhouse effect
Question 2/3

Type your answer to the question below.

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.

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 periodicals the increased carbon dioxide emission is often stated as the main source of the temperature rise in the twentieth century.

Figure 2.15 ■ **GREENHOUSE presented onscreen: Question 3**

PISA 2015   ? ⬅ ➡

2

Greenhouse effect
Question 3/3

Type your answer to the question below.

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.

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 periodicals the increased carbon dioxide emission is often stated as the main source of the temperature rise in the twentieth century.

Science example 2: SMOKING

This new 2015 exemplar unit explores various forms of evidence linked to the harmful effects of smoking and the methods used to help people to stop smoking. New scientific literacy items for 2015 are only developed for computer-based delivery and therefore this exemplar is only shown in an onscreen format.

All onscreen standard question types in the PISA 2015 computer platform have a vertical split screen with the stimuli presented on the right side and the questions and answer mechanisms on the left side.

Figure 2.16 ■ **SMOKING: Question 1**

PISA 2015   Unit Name: SMOKING

Question 1/9

John and Rose are researching cigarette smoking for a school project.
Read John's research on the right. Then respond to the question below.
Select **two** reasons from the list below that suggest why cigarette companies could claim there was **no** evidence that tar from cigarette smoke caused cancer in humains.

☐ Humans are immune to tar
☐ Experiments were carried out with mice
☐ Chemicals from smoking decreased the effects of tar
☐ Humans may react differently from mice
☐ Filter-tip cigarettes remove all tar from smoke

John's research

In the 1950s research studies found that tar from cigarette smoke caused cancer in mice. Tobacco companies claimed there was no evidence that smoking caused cancer in humains. They also began to produce filter-tip cigarettes.

SMOKING – *QUESTION 1*

This question requires students to interpret given evidence using their knowledge of scientific concepts. They need to read the information in the stimulus about early research into the potential harmful effects of smoking, and then select two options from the menu to answer the question.

In this question, students have to apply content knowledge using the competency of "explaining phenomena scientifically". The context is categorised as "health and disease" in a local/national setting. The cognitive demand requires the use and application of conceptual knowledge and is therefore categorised as a medium level of demand.

Figure 2.17 ▪ **Framework categorisation for SMOKING question 1**

Framework categories	2015 Framework
Knowledge type	Content
Competency	Explaining phenomena scientifically
Context	Health and disease, local and national
Cognitive demand	Medium

SMOKING – *QUESTION 2*

This question explores students' understanding of data.

The right side of the screen shows authentic data of cigarette consumption and deaths from lung cancer in men over an extended period of time. Students are asked to select the best descriptor of the data by clicking on one of the radio buttons next to answer statements on the left side of the screen.

Figure 2.18 ▪ **SMOKING: Question 2**
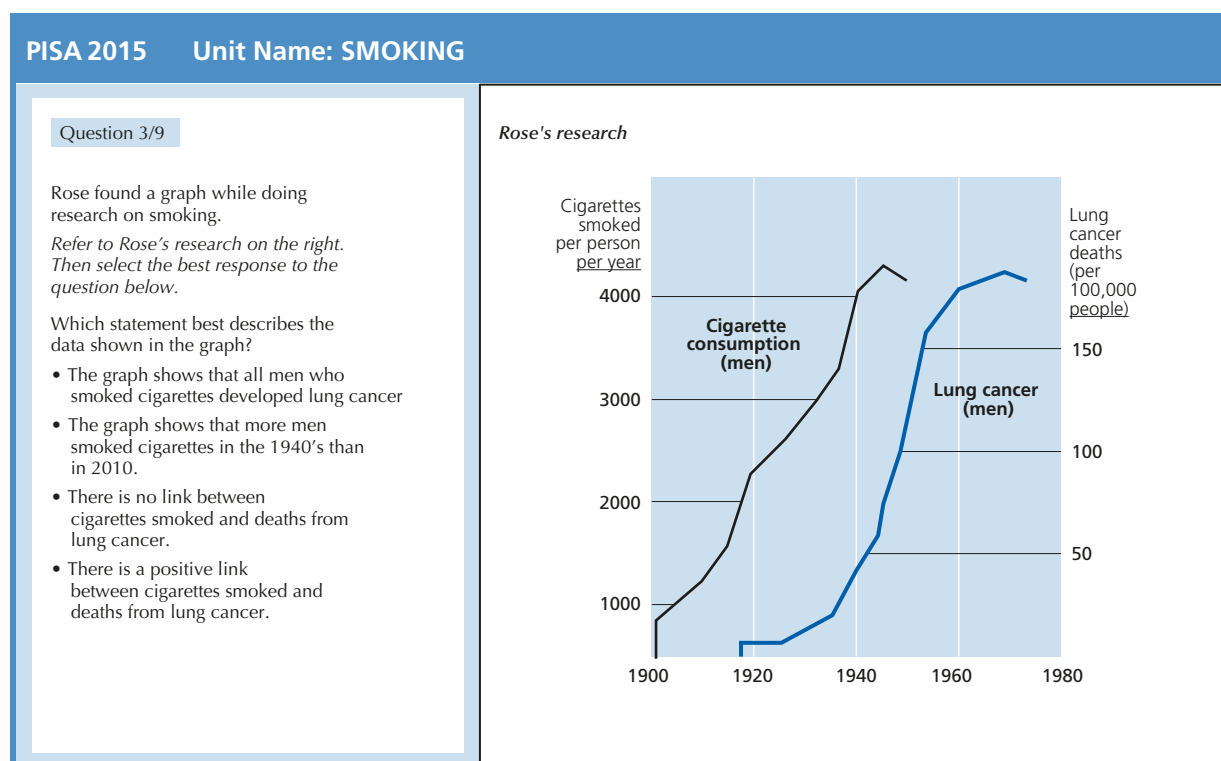
This unit tests content knowledge using the competency of "interpreting data and evidence scientifically".

The context is "health and disease" applied to a local/national setting. As students need to interpret the relationship between two graphs, the cognitive demand is categorised as medium.

Figure 2.19 ■ **Framework categorisation for SMOKING question 2**

Framework categories	2015 Framework
Knowledge type	Content
Competency	Interpret data and evidence scientifically
Context	Health and disease, local and national
Cognitive demand	Medium

Science example 3: ZEER POT

This new 2015 exemplar unit features the use of interactive tasks using simulations of scientific enquiry to explore and assess scientific literacy knowledge and competencies.

This unit focuses on an authentic low-cost cooling container called a Zeer pot, developed for local use in Africa, using readily available local resources. Cost and lack of electricity limit the use of refrigerators in these regions, even though the hot climate requires that people keep food cool so that it can be kept for a longer time before bacterial growth renders it a risk to health.

The first screen shot of this simulation introduces what a Zeer pot looks like and how it works. Students are not expected to have an understanding of how the process of evaporation causes cooling, just that it does.

Using this simulation, students are asked to investigate the conditions that will produce the most effective cooling effects (4°C) for keeping food fresh in the Zeer pot. The simulator keeps certain conditions constant (the air temperature and the humidity), but includes this information to enhance the authentic contextual setting. In the first question, students are asked to investigate the optimum conditions to keep the maximum amount of food fresh in the Zeer pot by altering the thickness of the sand layer and the moisture conditions.

Figure 2.20 ■ **ZEER POT: Stimulus**

PISA 2015   Unit name: ZEER POT

Introduction

A zeer pot refrigeration is an invention to keep food cool without electricity, usually found in African countries.

A small clay pot sits inside a larger clay pot with a clay or fabric lid. The space between the two pots is filled with sand.This creates an insulating layer around the inner pot. The sand is kept damp by adding water at regular intervals. When the water evaporates, the temperature in the inner pot is reduced.

Local people make zeer pots out of clay, a locally available resource.

ZEER POT

Inner clay pot. Food is placed here

Layer of damp sand

Outer clay pot

Clay or fabric lid

Stand

Figure 2.21 ▪ **ZEER POT: Question 1**
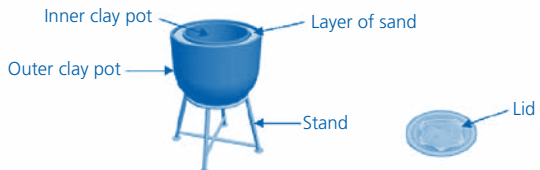
PISA 2015   Unit name: ZEER POT

Task 1

You have been asked to investigate the best design of a Zeer pot for a family to keep their food fresh.

Food is best kept at a temperature of **4°C** to maximise freshness and minimise bacterial growth.

Use the simulator opposite to work out the maximum amount of food that can be kept fresh (at 4°C) by varying the thickness and moisture condition of the sand layer.

You can run a number of simulations, and repeat or remove any data findings.

Maximum amount of food kept fresh

at 4°C is   kg

When students have set their conditions (which also alter the visual display of the on screen Zeer pot), they press the record-data button, which then runs the simulation and populates the data chart. They need to run a number of data simulations, and can remove data or repeat any simulations as required. This screen then records their response to the maximum amount of food kept fresh at 4°C. Their approaches to the design and evaluation of this form of scientific enquiry can be assessed in subsequent questions.

The knowledge categorisation for this item is "procedural", and the competence is "evaluate and design scientific enquiry". The context categorisation is "natural resources", although it also has links to "health and disease". The cognitive demand of this question is categorised as high because students are given a complex situation, and they need to develop a systematic sequence of investigations to answer the question.

Figure 2.22 ▪ **Framework categorisation for ZEERPOT question 1**

Framework categories	2015 Framework
Knowledge type	Procedural
Competency	Evaluate and design scientific enquiry
Context	Natural resources
Cognitive demand	High

Attitudes

Why attitudes matter

Peoples' attitudes towards science play a significant role in their interest, attention and response to science and technology, and to issues that affect them specifically. One goal of science education is to develop attitudes that lead students to engage with scientific issues. Such attitudes also support the subsequent acquisition and application of scientific and technological knowledge for personal, local/national and global benefit, and lead to the development of self-efficacy (Bandura, 1997).

Attitudes form part of the construct of scientific literacy. That is, a person's scientific literacy includes certain attitudes, beliefs, motivational orientations, self-efficacy and values. The construct of attitudes used in PISA draws upon Klopfer's (1976) structure for the affective domain in science education and reviews of attitudinal research (Gardner, 1975; Osborne, Simon and Collins, 2003; Schibeci, 1984). A major distinction made in these reviews is between attitudes towards science and scientific attitudes. While the former is measured by the level of interest displayed in scientific issues and activities, the latter is a measure of a disposition to value empirical evidence as the basis of belief.

Defining attitudes towards science in PISA 2015

The PISA 2015 assessment evaluates students' attitudes towards science in three areas: interest in science and technology, environmental awareness, and valuing scientific approaches to enquiry (see Figure 2.23), which are considered core to the construct of scientific literacy. These three areas were selected for measurement because a positive attitude towards science, a concern for the environment and an environmentally sustainable way of life, and a disposition to value the scientific approach to enquiry are characteristics of a scientifically literate individual. Thus, the extent to which individual students are, or are not interested in science and recognise its value and implications is considered an important measure of the outcome of compulsory education. Moreover, in 52 of the countries (including all OECD countries) that participated in PISA 2006, students with a higher general interest in science performed better in science (OECD, 2007:143).

Interest in science and technology was selected because of its established relationships with achievement, course selection, career choice and lifelong learning. For instance, there is a considerable body of literature which shows that interest in science is established by age 14 for the majority of students (Ormerod and Duckworth, 1975; Tai et al., 2006). Moreover, students with such an interest are more likely to pursue scientific careers. Policy concerns in many OECD countries about the number of students, particularly girls, who choose to pursue the study of science make the measurement of attitudes towards science an important aspect of the PISA assessment. The results may provide information about a perceived declining interest in the study of science among young people (Bøe et al., 2011). This measure, when correlated with the large body of other information collected by PISA through the student, teacher and school questionnaires, may provide insights into the causes of any decline in interest.

Valuing scientific approaches to enquiry was chosen because scientific approaches to enquiry have been highly successful at generating new knowledge – not only within science itself, but also in the social sciences, and even finance and sports. Moreover, the core value of scientific enquiry and the Enlightenment is the belief in empirical evidence as the basis of rational belief. Recognising the *value of the scientific approach to enquiry* is, therefore, widely regarded as a fundamental objective of science education that warrants assessing.

Appreciation of, and support for, scientific enquiry implies that students can identify and also value scientific ways of gathering evidence, thinking creatively, reasoning rationally, responding critically and communicating conclusions as they confront life situations related to science and technology. Students should understand how scientific approaches to enquiry function, and why they have been more successful than other methods in most cases. Valuing scientific approaches to enquiry, however, does not mean that an individual has to be positively disposed towards all aspects of science or even use such methods themselves. Thus, the construct is a measure of students' attitudes towards the use of a scientific method to investigate material and social phenomenon and the insights that are derived from such methods.

Environmental awareness is of international concern, as well as being of economic relevance. Attitudes in this area have been the subject of extensive research since the 1970s (see, for example, Bogner and Wiseman, 1999; Eagles and Demare, 1999; Rickinson, 2001; Weaver, 2002). In December 2002, the United Nations approved resolution 57/254 declaring the ten-year period beginning on 1 January 2005 to be the United Nations Decade of Education for Sustainable Development (UNESCO, 2003). The International Implementation Scheme (UNESCO, 2005) identifies the environment as one of the three spheres of sustainability (along with society, including culture, and economy) that should be included in all education programmes for sustainable development.

Given the importance of environmental issues to the continuation of life on Earth and the survival of humanity, young people today need to understand the basic principles of ecology and the need to organise their lives accordingly. This means that developing environmental awareness and a responsible disposition towards the environment is an important element of contemporary science education.

In PISA 2015 these specific attitudes towards science are measured through the student questionnaire. Further detail of these constructs can be found in the Questionnaire framework, Chapter 5.

ASSESSING SCIENTIFIC LITERACY

Cognitive demand

A key new feature of the PISA 2015 framework is the definition of levels of cognitive demand within the assessment of scientific literacy and across all three competencies of the framework. In assessment frameworks, item difficulty, which is empirically derived, is often confused with cognitive demand. Empirical item difficulty is estimated from the proportion of test-takers who solve the item correctly, and thus assesses the amount of knowledge held by the test-taker population, whereas cognitive demand refers to the type of mental processes required (Davis and Buckendahl, 2011). Care needs to be taken to ensure that the depth of knowledge required, i.e. the cognitive demand test items, is understood explicitly by the item developers and users of the PISA framework. For instance, an item can have high difficulty because the knowledge it is testing is not well known, but the cognitive demand is simply recall. Conversely, an item can be cognitively demanding because it requires the individual to relate and evaluate many items of knowledge – each of which is easily recalled. Thus, not only should the PISA test instrument discriminate in terms of performance between easier and harder test items, the test also needs to provide information on how students across the ability range can deal with problems at different levels of cognitive demand (Brookhart and Nitko, 2011).

The competencies are articulated using a range of terms defining cognitive demand through the use of verbs such as "recognise", "interpret", "analyse" and "evaluate". However, in themselves these verbs do not necessarily indicate a hierarchical order of difficulty that is dependent on the level of knowledge required to answer any item. Various classifications of cognitive demand schemes have been developed and evaluated since Bloom's Taxonomy was first published (Bloom, 1956). These have been largely based on categorisations of knowledge types and associated cognitive processes that are used to describe educational objectives or assessment tasks.

Bloom's revised Taxonomy (Anderson and Krathwohl, 2001) identifies four categories of knowledge – factual, conceptual, procedural and meta-cognitive. This categorisation considers these forms of knowledge to be hierarchical and distinct from the six categories of performance used in Bloom's first taxonomy – remembering, understanding, applying, analysing, evaluating and creating. In Anderson and Krathwohl's framework, these two dimensions are now seen to be independent of each other, allowing for lower levels of knowledge to be crossed with higher order skills, and vice versa.

A similar framework is offered by Marzano and Kendall's Taxonomy (2007), which also provides a two-dimensional framework based on the relationship between how mental processes are ordered and the type of knowledge required. The use of mental processes is seen as a consequence of a need to engage with a task with meta-cognitive strategies that define potential approaches to solving problems. The cognitive system then uses either retrieval, comprehension, analysis or knowledge utilisation. Marzano and Kendall divide the knowledge domain into three types of knowledge, information, mental procedures and psychomotor, compared to the four categories in Bloom's revised Taxonomy. Marzano and Kendall argue that their taxonomy is an improvement upon Bloom's Taxonomy because it offers a model of how humans actually think rather than simply an organising framework.

A different approach is offered by Ford and Wargo (2012), who offer a framework for scaffolding dialogue as a way of considering cognitive demand. Their framework uses four levels that build on each other: recall, explain, juxtapose and evaluate. Although this framework has not been specifically designed for assessment purposes, it has many similarities to the PISA 2015 definition of scientific literacy and the need to make more explicit references to such demands in the knowledge and competencies.

Another schema can be found in the framework based on Depth of Knowledge developed by Webb (1997) specifically to address the disparity between assessments and the expectations of student learning. For Webb, levels of depth can be determined by taking into account the complexity of both the content and the task required. His schema consists of four major categories: level 1 (recall), level 2 (using skills and/or conceptual knowledge), level 3 (strategic thinking) and level 4 (extended thinking). Each category is populated with a large number of verbs that can be used to describe cognitive processes. Some of these appear at more than one level. This framework offers a more holistic view of learning and assessment tasks, and requires an analysis of both the content and cognitive process demanded by any task. Webb's Depth of Knowledge (DOK) approach is a simpler but more operational version of the SOLO Taxonomy (Biggs and Collis, 1982) which describes a continuum of student understanding through five distinct stages of pre-structural, unistructural, multistructural, relational and extended abstract understanding.

All the frameworks described briefly above have served to develop the knowledge and competencies in the PISA 2015 Framework. In drawing up such a framework, it is recognised that there are challenges in developing test items based on a cognitive hierarchy. The three main challenges are that:

a) Too much effort is made to fit test items into particular cognitive frameworks, which can lead to poorly developed items.

b) Intended items (with frameworks defining rigorous, cognitively demanding goals) may differ from actual items (which may operationalise the standard in a much less cognitively demanding way).

c) Without a well-defined and understood cognitive framework, item writing and development often focuses on item difficulty and uses a limited range of cognitive processes and knowledge types, which are then only described and interpreted post hoc, rather than building from a theory of increasing competency.

The approach taken in this framework is to use an adapted version of Webb's Depth of Knowledge grid (Webb, 1997) alongside the desired knowledge and competencies. As the competencies are the central feature of the framework, the cognitive framework needs to assess and report on them across the student ability range. Webb's Depth of Knowledge Levels offer a taxonomy for cognitive demand that requires items to identify both the cognitive demand from the verbal cues that are used, e.g. analyse, arrange, compare, and the expectations of the depth of knowledge required.

Figure 2.23 ▪ **PISA 2015 Framework for Cognitive Demand**

The grid in Figure 2.23 provides a framework for mapping items against the two dimensions of knowledge and competencies. In addition, each item can also be mapped using a third dimension based on a depth-of-knowledge taxonomy. This provides a means of operationalising cognitive demand as each item can be categorised as making demands that are:

▪ **Low**
    Carry out a one-step procedure, for example recall a fact, term, principle or concept, or locate a single point of information from a graph or table.

▪ **Medium**
    Use and apply conceptual knowledge to describe or explain phenomena, select appropriate procedures involving two or more steps, organise/display data, interpret or use simple data sets or graphs.

▪ **High**
    Analyse complex information or data; synthesise or evaluate evidence; justify; reason, given various sources; develop a plan or sequence of steps to approach a problem.

The distribution of items by depth of knowledge is described in Table 2.5.

Table 2.5 Distribution of items by depth of knowledge

Depth of knowledge	Percentage of items
Low	8
Medium	30
High	61
Total	**100**

Items that merely require recall of one piece of information make low cognitive demands, even if the knowledge itself might be quite complex. In contrast, items that require recall of more than one piece of knowledge, and require a comparison and evaluation of the competing merits of their relevance would be seen as having high cognitive demand. The difficulty of any item, therefore, is a combination both of the degree of complexity and range of knowledge it requires, and the cognitive operations that are required to process the item.

Therefore, the factors that determine the demand of items assessing science achievement include:

- The number and degree of complexity of elements of knowledge demanded by the item.
- The level of familiarity and prior knowledge that students may have of the content, procedural and epistemic knowledge involved.
- The cognitive operation required by the item, e.g. recall, analysis, evaluation.
- The extent to which forming a response is dependent on models or abstract scientific ideas.

This four-factor approach allows for a broader measure of scientific literacy across a wider range of student ability. Categorising the cognitive processes required for the competencies that form the basis of scientific literacy together with a consideration of the depth of knowledge required offers a model for assessing the level of demand of individual items. In addition, the relative simplicity of the approach offers a way to minimise the problems encountered in applying such frameworks. The use of this cognitive framework also facilitates the development of an a priori definition of the descriptive parameters of the reporting proficiency scales (see Figure 2.25).

Test characteristics

Figure 2.24 is a variation of Figure 2.2 that presents the basic components of the PISA framework for the 2015 scientific literacy assessment in a way that can be used to relate the framework with the structure and the content of assessment units. This may be used as a tool both to plan assessment exercises and to study the results of standard assessment exercises. As a starting point to construct assessment units, it shows the need to consider the contexts that will serve as stimulus material, the competencies required to respond to the questions or issues, the knowledge central to the exercise, and the cognitive demand.

Figure 2.24 ▪ **A tool for constructing and analysing assessment units and items**
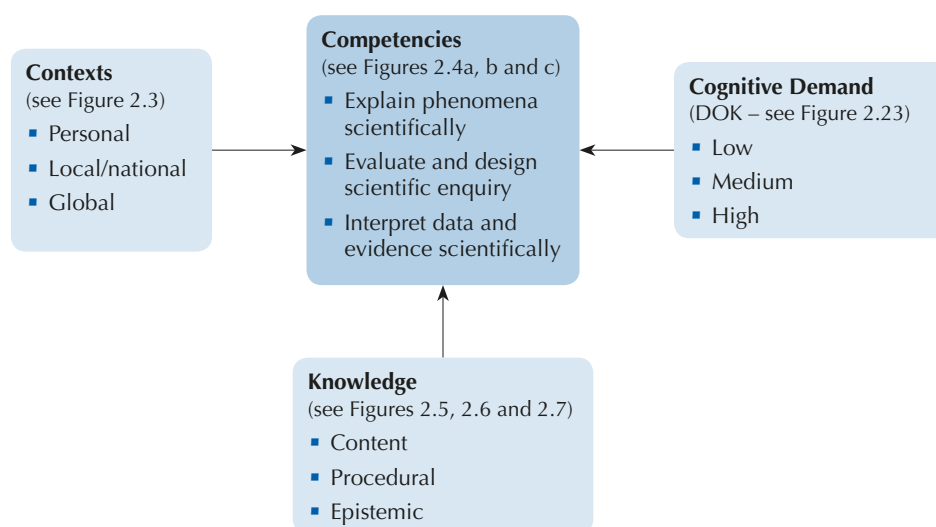
A test unit is defined by specific stimulus material, which may be a brief written passage, or text accompanying a table, chart, graph or diagram. In units created for PISA 2015, the stimulus material may also include non-static stimulus material, such as animations and interactive simulations. The items are a set of independently scored questions of various types, as illustrated by the examples already discussed. Further examples can be found at the PISA website (www.oecd.org/pisa/) (November 2016).

PISA uses this unit structure to facilitate the use of contexts that are as realistic as possible, reflecting the complexity of real-life 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 in each question. However, the need to make each score 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 2015 test units require the use of all three scientific competencies and draw on all three forms of science knowledge. In most cases, each test unit assesses multiple competencies and knowledge categories. Individual items, however, assess only one form of knowledge and one competency.

The need for students to read texts in order to understand and answer written questions on scientific literacy raises an issue of the level of reading literacy that are required. Stimulus material and questions use language that is as clear, simple and brief, and as syntactically simplified as possible while still conveying the appropriate meaning. The number of concepts introduced per paragraph is limited. Questions within the domain of science that assess reading or mathematical literacy are avoided.

Response formats

Three classes of items are used to assess the competencies and scientific knowledge identified in the framework. About one-third of the items are in each of the three classes:

- simple multiple choice: items calling for
  - selection of a single response from four options
  - selection of a "hot spot", an answer that is a selectable element within a graphic or text

- complex multiple choice: items calling for
  - responses to a series of related "Yes/No" questions that are treated for scoring as a single item (the typical format in 2006)
  - selection of more than one response from a list
  - completion of a sentence by selecting drop-down choices to fill multiple blanks
  - "drag-and-drop" responses, allowing students to move elements on screen to complete a task of matching, ordering or categorising

- constructed response: items calling for written or drawn responses
  - Constructed-response items in scientific literacy typically call for a written response ranging from a phrase to a short paragraph (e.g. two to four sentences of explanation). A small number of constructed-response items call for drawing (e.g. a graph or diagram). In a computer-based assessment, any such item is supported by simple drawing editors that are specific to the response required.

In 2015, some responses are captured by interactive tasks, for example, a student's choices for manipulating variables in a simulated scientific enquiry. Responses to these interactive tasks are likely scored as complex multiple-choice items. Some kinds of responses to interactive tasks may be sufficiently open-ended that they are treated as constructed response.

Assessment structure

Computer is the primary mode of delivery for all domains, including scientific literacy, in PISA 2015. All new science literacy items are only available on computer. However a paper-based assessment instrument, consisting only of the trend items, is provided for countries choosing not to test their students by computer. (The PISA 2015 field trial studied the effect on student performance of the change in mode of delivery. For further details see Box 1.2.)

Scientific literacy items are organised into 30-minute sections called "clusters". Each cluster includes either only new units or only trend units. Overall for 2015, the target number of clusters included in the main survey is:

- six clusters of trend units in 2015 main survey
- six clusters of new units in 2015 main survey.

Each student is assigned one two-hour test form. A test form is composed of four clusters, with each cluster designed to occupy thirty minutes of testing time. The clusters are placed in multiple computer-based test forms, according to a rotated test design.

Each student spends one hour on scientific literacy, with the remaining time assigned to either one or two of the additional domains of reading, mathematics and collaborative problem solving. For any countries taking the paper-based assessment instrument, intact clusters of 2006 units are formed into a number of test booklets. The paper-based assessment is limited to trend items and does not include any newly developed material. In contrast, the computer-based instrument includes newly developed items as well as trend items. When transposing paper-based trend items to an onscreen format, the presentation, response format and cognitive demand remain comparable.

Item contexts are spread across personal, local/national and global settings roughly in the ratio 1:2:1, as was the case in 2006. A wide selection of areas of application are used for units, subject to satisfying as far as possible the various constraints imposed by the distribution of items shown in Tables 2.1 and 2.4.

Reporting proficiency in science

To achieve the aims of PISA, scales must be developed to measure student proficiency. A descriptive scale of levels of competence needs to be based on a theory of how the competence develops, not just on a post-hoc interpretation of what items of increasing difficulty seem to be measuring. The 2015 draft framework therefore defined explicitly the parameters of increasing competence and progression, allowing item developers to design items representing this growth in ability (Kane, 2006; Mislevy and Haertel, 2006). Initial draft descriptions of the scales are offered below, though it is recognised that these may need to be updated after the main survey. Although comparability with the 2006 scale descriptors (OECD, 2007) has been maximised in order to enable trend analyses, the new elements of the 2015 framework, such as depth of knowledge, have also been incorporated. The scales have also been extended by the addition of a level "1b" to specifically address and provide a description of students at the lowest level of ability who demonstrate minimal scientific literacy and would previously not have been included in the reporting scales. The initial draft scales for 2015 Framework therefore propose more detailed and more specific descriptors of the levels of scientific literacy, and not an entirely different model as shown in Figure 2.25.

Figure 2.25 ▪ **Initial draft of proficiency scale descriptions for science**

Level	Descriptor
6	At Level 6, students are able to use content, procedural and epistemic knowledge to consistently provide explanations, evaluate and design scientific enquiries, and interpret data in a variety of complex life situations that require a high level of cognitive demand. They can draw appropriate inferences from a range of different complex data sources, in a variety of contexts and provide explanations of multi-step causal relationships. They can consistently distinguish scientific and non-scientific questions, explain the purposes of enquiry, and control relevant variables in a given scientific enquiry or any experimental design of their own. They can transform data representations, interpret complex data and demonstrate an ability to make appropriate judgments about the reliability and accuracy of any scientific claims. Level 6 students consistently demonstrate advanced scientific thinking and reasoning requiring the use of models and abstract ideas and use such reasoning in unfamiliar and complex situations. They can develop arguments to critique and evaluate explanations, models, interpretations of data and proposed experimental designs in a range of personal, local and global contexts.
5	At Level 5, students are able to use content, procedural and epistemic knowledge to provide explanations, evaluate and design scientific enquiries and interpret data in a variety of life situations in some but not all cases of high cognitive demand. They draw inferences from complex data sources, in a variety of contexts and can explain some multi-step causal relationships. Generally, they can distinguish scientific and non-scientific questions, explain the purposes of enquiry, and control relevant variables in a given scientific enquiry or any experimental design of their own. They can transform some data representations, interpret complex data and demonstrate an ability to make appropriate judgments about the reliability and accuracy of any scientific claims. Level 5 students show evidence of advanced scientific thinking and reasoning requiring the use of models and abstract ideas and use such reasoning in unfamiliar and complex situations. They can develop arguments to critique and evaluate explanations, models, interpretations of data and proposed experimental designs in some but not all personal, local and global contexts.

...

Figure 2.25 [continued] ▪ **Initial draft of proficiency scale descriptions for science**

4	At Level 4, students are able to use content, procedural and epistemic knowledge to provide explanations, evaluate and design scientific enquiries and interpret data in a variety of given life situations that require mostly a medium level of cognitive demand. They can draw inferences from different data sources, in a variety of contexts and can explain causal relationships. They can distinguish scientific and non-scientific questions, and control variables in some but not all scientific enquiry or in an experimental design of their own. They can transform and interpret data and have some understanding about the confidence held about any scientific claims. Level 4 students show evidence of linked scientific thinking and reasoning and can apply this to unfamiliar situations. Students can also develop simple arguments to question and critically analyse explanations, models, interpretations of data and proposed experimental designs in some personal, local and global contexts.
3	At Level 3, students are able to use content, procedural and epistemic knowledge to provide explanations, evaluate and design scientific enquiries and interpret data in some given life situations that require at most a medium level of cognitive demand. They are able to draw a few inferences from different data sources, in a variety of contexts, and can describe and partially explain simple causal relationships. They can distinguish some scientific and non-scientific questions, and control some variables in a given scientific enquiry or in an experimental design of their own. They can transform and interpret simple data and are able to comment on the confidence of scientific claims. Level 3 students show some evidence of linked scientific thinking and reasoning, usually applied to familiar situations. Students can develop partial arguments to question and critically analyse explanations, models, interpretations of data and proposed experimental designs in some personal, local and global contexts.
2	At Level 2, students are able to use content, procedural and epistemic knowledge to provide explanations, evaluate and design scientific enquiries and interpret data in some given familiar life situations that require mostly a low level of cognitive demand. They are able to make a few inferences from different sources of data, in few contexts, and can describe simple causal relationships. They can distinguish some simple scientific and non-scientific questions, and distinguish between independent and dependent variables in a given scientific enquiry or in a simple experimental design of their own. They can transform and describe simple data, identify straightforward errors, and make some valid comments on the trustworthiness of scientific claims. Students can develop partial arguments to question and comment on the merits of competing explanations, interpretations of data and proposed experimental designs in some personal, local and global contexts.
1a	At Level 1a, students are able to use a little content, procedural and epistemic knowledge to provide explanations, evaluate and design scientific enquiries and interpret data in a few familiar life situations that require a low level of cognitive demand. They are able to use a few simple sources of data, in a few contexts and can describe some very simple causal relationships. They can distinguish some simple scientific and non-scientific questions, and identify the independent variable in a given scientific enquiry or in a simple experimental design of their own. They can partially transform and describe simple data and apply them directly to a few familiar situations. Students can comment on the merits of competing explanations, interpretations of data and proposed experimental designs in some very familiar personal, local and global contexts.
1b	At Level 1b, students demonstrate a little evidence to use content, procedural and epistemic knowledge to provide explanations, evaluate and design scientific enquiries and interpret data in a few familiar life situations that require a low level of cognitive demand. They are able to identify straightforward patterns in simple sources of data in a few familiar contexts and can offer attempts at describing simple causal relationships. They can identify the independent variable in a given scientific enquiry or in a simple design of their own. They attempt to transform and describe simple data and apply them directly to a few familiar situations.

The proposed level descriptors are based on the 2015 Framework described in this document and offer a qualitative description of the differences between levels of performance. The factors used to determine the demand of items assessing science achievement that have been incorporated into this outline of the proficiency scales include:

▪ the number and degree of complexity of elements of knowledge demanded by the item

▪ the level of familiarity and prior knowledge that students may have of the content, procedural and epistemic knowledge involved

▪ the cognitive operation required by the item, e.g. recall, analysis, evaluation

▪ the extent to which forming a response is dependent on models or abstract scientific ideas.

References

American Association for the Advancement of Science (1989), *Science for all Americans: a Project 2061 Report on Literacy Goals in Science, Mathematics and Technology*, AAS Publishing, Washington, DC, www.project2061.org/publications/sfaa/online/sfaatoc.htm.

Anderson, L.W. and **D.R. Krathwohl** (2001), *A Taxonomy for Learning, Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*, Longman Publishing, London.

Bandura, A. (1997), *Self-Efficacy: The Exercise of Control,* W.H. Freeman and Company, Macmillan Publishers, New York.

Biggs, J. and **K. Collis** (1982), *Evaluating the Quality of Learning: The SOLO Taxonomy*, Academic Press, New York.

Bloom, B.S. (eds.) (1956), *Taxonomy of Educational Objectives Book 1: Cognitive Domain*, Longmans Publishing, London.

Bøe, M.V. et al. (2011), "Participation in science and technology: Young people's achievement-related choices in late-modern societies", *Studies in Science Education*, Vol. 47/1, pp. 37-72, http://dx.doi.org/10.1080/03057267.2011.549621.

Bogner, F. and **M. Wiseman** (1999), "Toward measuring adolescent environmental perception", *European Psychologist,* Vol. 4/3, http://dx.doi.org/10.1027//1016-9040.4.3.139.

Brookhart, S.M. and **A.J. Nitko** (2011), "Strategies for constructing assessments of higher order thinking skills", in G. Schraw and D.R. Robinson (eds.), *Assessment of Higher Order Thinking Skills*, IAP, Charlotte, NC, pp. 327-359.

Confederacion de Sociedades Cientificas de España (2011), *Informe ENCIENDE, Enseñanza de las Ciencias en la Didáctica Escolar para edades tempranas en España*, Madrid.

Davis, S.L. and **C.W. Buckendahl** (2011), "Incorporating cognitive demand in credentialing examinations", in G. Schraw and D.R. Robinson (eds), *Assessment of Higher Order Thinking Skills*, IAP, Charlotte, NC, pp. 327-359.

Drechsel, B., C. Carstensen and **M. Prenzel** (2011), "The role of content and context in PISA interest scales: A study of the embedded interest items in the PISA 2006 science assessment", *International Journal of Science Education*, Vol. 33/1, pp. 73-95.

Duschl, R. (2007), "Science education in three-part harmony: Balancing conceptual, epistemic and social learning goals", *Review of Research in Education*, Vol. 32, pp. 268-291, http://dx.doi.org/10.3102/0091732X07309371.

Eagles, P.F.J. and **R. Demare** (1999), "Factors influencing children's environmental attitudes", *The Journal of Environmental Education*, Vol. 30/4, www.researchgate.net/profile/Paul_Eagles/publication/271994465_Factors_Influencing_Children's_Environmental_Attitudes/links/553e677b0cf20184050f83a6.pdf.

European Commission (1995), "Teaching and learning: Towards the learning society", *White Paper on Education and Training*, Office for Official Publications in European Countries, Luxembourg, http://europa.eu/documents/comm/white_papers/pdf/com95_590_en.pdf.

Fensham, P. (1985), "Science for all: A reflective essay", *Journal of Curriculum Studies*, Vol. 17/4, pp. 415-435, http://dx.doi.org/10.1080/0022027850170407.

Ford, M.J. and **B.M. Wargo** (2012), "Dialogic framing of scientific content for conceptual and epistemic understanding", *Science Education*, Vol. 96/3, pp. 369-391, http://dx.doi.org/10.1002/sce.20482.

Gardner, P.L. (1975), "Attitudes to Science", *Studies in Science Education*, Vol. 2, pp. 1-41.

Gott, R., S. Duggan and **R. Roberts** (2008)," Concepts of evidence", University of Durham*,* www.dur.ac.uk/rosalyn.roberts/Evidence/cofev.htm, (accessed 23 September 2012).

Kane, M. (2006), "Validation", in R.L. Brennan (eds.), *Educational Measurement*, 4th ed., Praeger Publishers and the American Council on Education, Westport, CT, pp. 17-64.

Klopfer, L.E. (1971), "Evaluation of learning in science" in B.S. Bloom, J.T. Hastings and G.F. Madaus (eds.), *Handbook of Formative and Summative Evaluation of Student Learning*, McGraw-Hill Book Company, London.

Klopfer, L.E. (1976), "A structure for the affective domain in relation to science education", *Science Education*, Vol. 60/3, pp. 299-312, http://dx.doi.org/ 10.1002/sce.3730600304.

Kuhn, D. (2010), "Teaching and learning science as argument", *Science Education*, Vol. 94/5, pp. 810-824, http://dx.doi.org/10.1002/sce.20395.

Lederman, N.G. (2006), "Nature of science: Past, present and future", in S. Abell and N.G. Lederman (eds.), *Handbook of Research on Science Education*, Lawrence Erlbaum, Mawah, NJ, pp. 831-879.

Longino, H.E. (1990), *Science as Social Knowledge,* Princetown University Press, Princetown, NJ.

Marzano, R.J. and **J.S. Kendall** (2007), *The New Taxonomy of Educational Objectives*, Corwin Press, Thousand Oaks, CA.

Millar, R. (2006), "Twenty first century science: Insights from the design and implementation of a scientific literacy approach in school science", *International Journal of Science Education*, Vol. 28/13, pp. 1499-1521, http://dx.doi.org/ 10.1080/09500690600718344.

Millar, R. and **J.F. Osborn** (eds.) (1998), *Beyond 2000: Science Education for the Future*, School of Education, King's College, London, www.nuffieldfoundation.org/sites/default/files/Beyond%202000.pdf.

Millar, R. et al. (1995), "Investigating in the school science laboratory: Conceptual and procedural knowledge and their influence on performance", *Research Papers in Education*, Vol. 9/2, pp. 207-248, http://dx.doi.org/ 10.1080/0267152940090205.

Mislevy, R.J. and **G.D. Haertel** (2006), "Implications of evidence-centered design for educational testing", *Educational Measurement: Issues and Practice*, Vol. 25/4, pp. 6-20.

National Academy of Science (1995), *National Science Education Standards*, National Academy Press, Washington, DC.

National Research Council (2012), *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, Committee on a Conceptual Framework for New K-12 Science Education Standards, Board on Science Education, Division of Behavioral and Social Sciences and Education, Washington, DC.

National Research Council (2000), *Inquiry and the National Science Education Standards*, National Academy Press, Washington DC.

OECD (2012), "What kinds of careers do boys and girls expect for themselves?", *PISA in focus*, No 14, OECD Publishing, Paris, http://dx.doi.org/10.1787/5k9d417g2933-en.

OECD (2009), *PISA 2006 Technical Report*, PISA, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264048096-en.

OECD (2007), *PISA 2006: Science Competencies for Tomorrow's World: Volume 1: Analysis*, PISA, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264040014-en.

OECD (2006), *Assessing Scientific, Reading and Mathematical Literacy: A Framework for PISA 2006,* PISA, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264026407-en.

OECD (2004), *The PISA 2003 Assessment Framework: Mathematics, Reading, Science and Problem Solving Knowledge and Skills*, PISA, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264101739-en.

OECD (2000), *Measuring Student Knowledge and Skills: The PISA 2000 Assessment of Reading, Mathematical and Scientific Literacy*, PISA, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264181564-en.

OECD (1999), *Measuring Student Knowledge and Skills: A New Framework for Assessment*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264173125-en.

Ormerod, M.B. and **D. Duckworth** (1975), *Pupils' Attitudes to Science*, National Foundation for Educational Reasearch, Slough, UK.

Osborne, J.F. (2010), "Arguing to learn in science: The role of collaborative, critical discourse", *Science*, Vol. 328/5977, pp. 463-466, http://dx.doi.org/ 10.1126/science.1183944.

Osborne, J.F. and **J. Dillon** (2008), *Science Education in Europe: Critical Reflections,* Nuffield Foundation, London.

Osborne, J.F., S. Simon and **S. Collins** (2003), "Attitudes towards science: A review of the literature and its implications", *International Journal of Science Education*, Vol. 25/9, pp. 1049–1079, http://dx.doi.org/10.1080/0950069032000032199.

Rickinson, M. (2001), "Learners and learning in environmental education: A critical review of the evidence", *Environmental Education Research*, Vol. 7/3, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.454.4637&rep=rep1&type=pdf.

Rychen, D.S. and **L. H. Salganik** (eds.) (2003), *Definition and Selection of Key Competencies: Executive Summary*, Hogrefe Publishing, Göttingen, Germany.

Schibeci, R.A. (1984), "Attitudes to science: An update", *Studies in Science Education*, Vol. 11, pp. 26-59.

Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland (KMK) (2005), Bildungsstandards im Fach Biologie für den Mittleren Schulabschluss (Jahrgangsstufe 10).

Tai, R.H. et al. (2006), "Planning early for careers in science", *Science*, Vol. 312, pp. 1143-1145.

Taiwan Ministry of Education (1999), Curriculum outlines for "Nature science and living technology", Ministry of Education, Taipei, Taiwan.

UNEP (2012), *21 Issues for the 21st Century: Result of the UNEP Foresight Process on Emerging Environmental Issues,* United Nations Environment Programme (UNEP), Nairobi, Kenya, www.unep.org/pdf/Foresight_Report-21_Issues_for_the_21st_Century.pdf.

UNESCO (2003), "UNESCO and the international decade of education for sustainable development (2005-2015)", *UNESCO International Science, Technology and Environmental Education Newsletter*, Vol. XXVIII, No. 1-2, UNESCO, Paris.
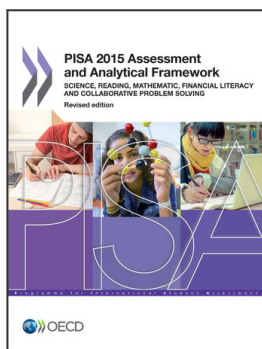
UNESCO (2005), "International implementation scheme" *United Nations Decade of Education for Sustainable Development (2005-2014)*, UNESCO, Paris, www.bibb.de/dokumente/pdf/a33_unesco_international_implementation_scheme.pdf.

Weaver, A. (2002), "Determinants of environmental attitudes: A five-country comparison", *International Journal of Sociology*, Vol. 32/1.

Webb, N.L. (1997), "Criteria for alignment of expectations and assessments in mathematics and science education", *Council of Chief State School Officers and National Institute for Science Education Research Monograph*, National Institution for Science Education, Washington, DC.

Wiliam, D. (2010), "What counts as evidence of educational achievement? The role of constructs in the pursuit of equity in assessment", *Review of Research in Education*, Vol. 34, pp. 254-284.

Ziman, J. (1979), *Reliable Knowledge: An Exploration of the Grounds for Belief in Science*, Cambridge University Press, Cambridge, UK.