4

PISA for Development Science Framework

This Chapter defines "scientific literacy" as assessed in the Programme for International Student Assessment (PISA) and the extensions to the PISA science framework that have been designed for the PISA for Development (PISA-D) project. It describes the types of contexts, knowledge and competencies reflected in PISA-D's science problems, and provides several sample items. The Chapter also discusses how student performance in science is measured and reported.

WHAT IS NEW IN PISA-D? EXTENSIONS TO THE PISA SCIENTIFIC LITERACY FRAMEWORK

This chapter presents the assessment framework for science in PISA-D and shows how it specifically addresses the needs and contexts of using PISA for assessing student competency in a wider range of countries. This chapter explains how the PISA 2015 science framework has been extended to provide more information regarding student performance at the lower levels of proficiency. While PISA-D's out-of-school component does not include the science domain, this framework is applicable for students who are in school as well as 15-year-olds who are out of school.

PISA establishes a baseline level – proficiency Level 2, on a scale with 6 as the highest level and 1b the lowest – at which individuals begin to demonstrate the competencies that will enable them to participate effectively and productively in life as students, workers and citizens. The extensions made to the PISA-D science framework are an attempt to gain more information about students who currently perform at or below Level 1. PISA-D builds on the PISA 2015 science framework, extending it to yet a lower level of performance (1c) to gather precise data on the science skills of the lowest performers. These extensions have been achieved by describing how the expectations of the three competencies – "Explain phenomena scientifically", "Evaluate and design scientific enquiry", and "Interpret data and evidence scientifically" – can help distinguish the differences between Level 1a, 1b and 1c students, based on increasing, but limited, cognitive demands. In general, all Level 1 items make less extensive demands on students' knowledge, and require less cognitive processing. In order to provide greater clarity, the document also explains what kinds of competencies and displays of understanding are not expected.

This chapter adds elements to indicate what it is reasonable to assess and what is expected of students who might perform at Levels 1 and 2 on the PISA scales, suggesting that assessment at these levels should be restricted, wherever possible, to items that make the lowest level of cognitive demand. In addition, to reduce the linguistic demands and cognitive load of any item, careful attention should be paid to simplifying the language of any item and removing extraneous text.

The PISA-D science framework adheres to the core idea of scientific literacy, as defined by PISA. The 1999, 2004 and 2006 PISA frameworks 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. The 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. In 2015 science was the main domain, and PISA-D has no main domains. So those sections that are not relevant to the PISA-D framework – and hence much of the discussion on attitudes – have been omitted or made briefer in this framework.

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" (EC, 1995, p.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. p.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 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?

This chapter is organised into the following sections. The first section, "Defining scientific literacy", explains the theoretical underpinnings of the PISA science assessment, including the formal definition of the scientific literacy construct and describing the three competencies required for scientific literacy. The second section, "Organising the domain of science", describes the four inter-related aspects that form the definition of scientific literacy: contexts, competencies, knowledge and attitudes. The third section, "Assessing scientific literacy", outlines the approach taken to apply the elements of the framework previously described, including cognitive demand, test characteristics, reporting proficiency, testing scientific literacy among the out-of-school population and examples of items for addressing the extended PISA-D Framework.

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 (AAAS, 1989; COSCE, 2011; Fensham, 1985; Millar and Osborne, 1998; National Research Council, 2012; 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 ability requires 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 and PISA-D is defined by the three competencies to:

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

All of these competencies require knowledge. Explaining scientific and technological phenomena, for instance, demands knowledge of the content of science (hereafter, content knowledge). The second and third competencies, however, require more than 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 require 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.

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.

Box 4.1 **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 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 et al., 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; 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 4.5, 4.6 and 4.7.

People need all three forms of scientific knowledge to perform the three competencies of scientific literacy. PISA 2015 and PISA-D focus on assessing the extent to which 15-year-olds are capable of displaying the three aforementioned competencies appropriately within 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 and PISA-D (see Box 4.2). 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 4.2 **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.
- **Interpret data and evidence scientifically** – analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions.
- **Evaluate and design scientific enquiry** – describe and appraise scientific investigations and propose ways of addressing questions scientifically.

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 the 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 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: 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 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 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.

Competency 3: 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.

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, 2000, 2003)

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. PISA-D does not include the measurement of attitudes towards learning science.

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

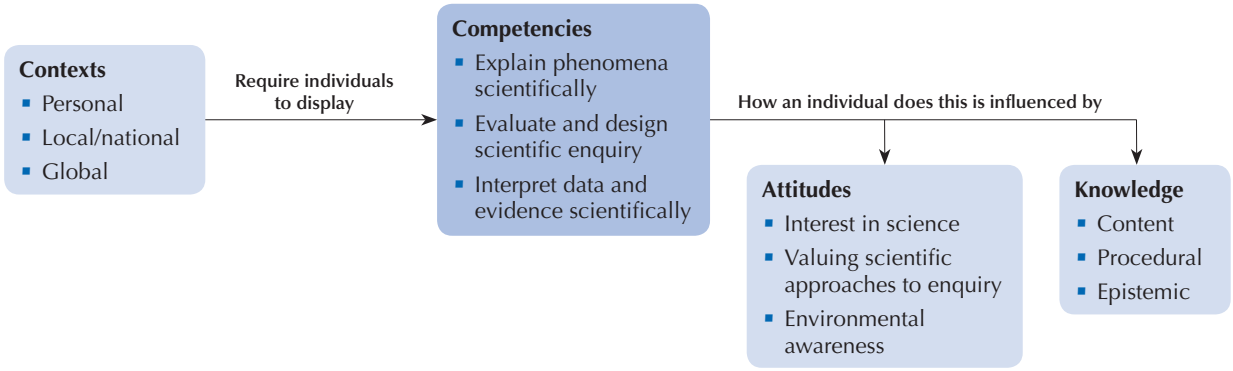
The PISA 2015 definition of scientific literacy used in PISA-D consists of four inter-related aspects (see Figures 4.1 and 4.2).

Figure 4.1 ▪ **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, interpret data and evidence scientifically, and evaluate and design scientific enquiry.
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.

Source: OECD (2016a), *PISA 2015 Assessment and Analytical Framework*, http://dx.doi.org/10.1787/9789264255425-en.

Figure 4.2 ▪ **Inter-relations between the four aspects**



Source: OECD (2016a), *PISA 2015 Assessment and Analytical Framework*, http://dx.doi.org/10.1787/9789264255425-en.

Contexts of assessment items

PISA 2015 and PISA-D assess 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 and PISA-D scientific literacy assessments, 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 4.3 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.

Figure 4.3 ▪ **Contexts in the PISA 2015 and PISA-D 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

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.

Scientific competencies

Figures 4.4a, 4.4c and 4.4e provide a detailed description of how students may display the three competencies required for scientific literacy. The set of scientific competencies in Figures 4.4a, 4.4c and 4.4e 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 4.4a ▪ **PISA 2015 and PISA-D 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.

For the purposes of assessing students who perform at Level 1, a more detailed description of this competency is defined beneath for PISA-D. All Level 1 students should be able to demonstrate some ability to explain phenomena scientifically.

Figure 4.4b ▪ **PISA-D Levels 1a, 1b and 1c for scientific competency "Explain phenomena scientifically"**

Explain phenomena scientifically for Level 1c
Recognise explanations for a limited range of the most simple natural and technological phenomena demonstrating the ability to: ▪ recall appropriate scientific knowledge.
Explain phenomena scientifically for Level 1b
Recognise explanations for a range of simple or familiar natural and technological phenomena demonstrating the ability to: ▪ identify an explanatory model or representation ▪ recognise the potential implications of scientific knowledge for society and individuals.
Explain phenomena scientifically for Level 1a
Recognise explanations for a range of simple or familiar natural and technological phenomena demonstrating the ability to: ▪ make appropriate predictions ▪ recognise an appropriate explanatory hypothesis ▪ recognise simple causal or correlational relationships.

At Level 1c students can be required to:

- identify what the elements are of a standard representation used in science. For instance, a question might present an unlabelled diagram of an object and students could be asked to add the appropriate labels from a list provided by the question.
- recall appropriate scientific knowledge but not apply such knowledge. For instance, a student might be asked to identify which scientific phenomenon is being described in an item.

At Level 1b students can be required to:

- recall appropriate scientific knowledge but not to apply such knowledge. For instance, a question might ask which one of several familiar scientific concepts from a list would explain a simple phenomenon described at the beginning of the question.
- use a familiar piece of scientific knowledge. For instance, a question about the freezing point of water might ask students to determine whether water will freeze in a given context.

At Level 1a students can be required to:

- make a simple prediction but not justify it. For instance, a question might ask which of several predictions might be correct, or students could be asked to predict the reading of an ammeter on a simple circuit where the reading on one ammeter is provided and the other is not.
- to identify from a list which evidence supports a particular claim, e.g. that a rock is a sedimentary rock or that a whale is a mammal rather than a fish.
- provide descriptive explanations of the properties of objects or substances – for instance that a rock must be sedimentary because it can be easily scratched.

The following requirements, however, would be considered too advanced and beyond the scope of a Level 1 competency; students would only be expected to attain partial credit on an item. Thus competency at this level would not require students to:

- offer explanatory hypotheses, or explain the potential implications of scientific knowledge for society
- construct an explanation for why a given explanation might be flawed
- offer explanatory hypotheses that require students to recall knowledge and draw an appropriate inference
- provide a causal explanation for how a device works
- identify an explanatory model in a question that requires the recall of more than two pieces of knowledge
- provide explanations of unfamiliar phenomena.

Figure 4.4c ■ **PISA 2015 and PISA-D 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.

The higher cognitive demand required to interpret data and evidence scientifically means that this competency is generally above Level 1c. More detailed descriptions of this competency for Levels 1a and 1b are provided below for PISA-D.

Figure 4.4d ■ **PISA-D Levels 1a and 1b for scientific competency "Interpret data and evidence scientifically"**

Interpret data and evidence scientifically for Level 1b
Recognise a specific scientific claim, justification or data set in a simple or familiar context, demonstrating the ability to: ▪ identify the evidence, claim or justification in a science-related text ▪ identify simple patterns in data.
Interpret data and evidence scientifically for Level 1a
Recognise specific scientific data, claims and justifications in simple or familiar contexts, and identify an appropriate conclusion, demonstrating the ability to: ▪ recognise an appropriate conclusion that can be drawn from a simple set of data ▪ extract a specific piece of information from a scientific text ▪ interpret graphical and visual data ▪ identify simple causal or correlational relationships.

At Level 1b students can be required to:

- describe a simple trend in data, but not be asked to draw a conclusion based on the data. For instance, a question might be asked to identify how temperatures have changed over a period of time when provided data in a graph or table.
- identify a claim, evidence or a reason in a science-related text. Alternatively, students could be asked to identify which is the claim, evidence or reasoning in a science text from a list that is provided.

At Level 1a students can be required to:

- state which one of several conclusions about a simple phenomenon drawn from a data set is the most appropriate, using a deduction requiring one step
- given a simple table, graph or other form of data representation, identify which conclusion or prediction is correct, e.g. identifying trends in a graph where there is no extraneous information
- extract meaning from simple scientific texts, for instance, asking students to identify the states through which matter moves, e.g. about solids, liquids and gases
- identify whether the conclusion drawn from a table of results, graph or other form of data is justified or not, e.g. whether the interpretation drawn from a table of materials and the effect of a magnet on the material is correct.

However, the following requirements would be considered too advanced and beyond the scope of a Level 1 competency; students would only be expected to attain partial credit on an item. Thus competency at this level would not require students to:

- distinguish between arguments that are based on scientific evidence or scientific theories and those that are based on other considerations
- evaluate two competing arguments from different sources (e.g. newspaper, Internet, journals)
- analyse or interpret more than one data set in any question
- consider multiple pieces of evidence or multiple theories and whether the information supports one or more theories.

Table 4.1 shows the desired distribution of items, by competency, for the PISA 2015 science assessment and for PISA-D. For science, the desired distributions for PISA-D are for the school-based instrument only, as science is not included in the out-of-school assessment.

Figure 4.4e ■ **PISA 2015 and PISA-D 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.

The higher cognitive demand required to evaluate and design scientific enquiry means that this competency is generally above Level 1c and attained only to a limited extent by Level 1b students. More detailed descriptions of this competency for Levels 1a and 1b are provided below for PISA-D.

Figure 4.4f ■ **PISA-D Levels 1a and 1b for scientific competency "Evaluate and design scientific enquiry"**

Evaluate and design scientific enquiry for Level 1b
Appraise simple scientific investigations, demonstrating the ability to: ▪ carry out a simple scientific procedure when provided explicit instructions ▪ determine which of several variables is the dependent variable in an investigation. ▪ recognise appropriate measures for a quantity (units appropriate for measuring).
Evaluate and design scientific enquiry for Level 1a
Appraise simple scientific investigations and recognise ways of addressing questions scientifically, demonstrating the ability to: ▪ identify the question explored in a simple scientific study ▪ distinguish a question that is possible to investigate scientifically from one that is not ▪ evaluate if one way of exploring a given question is scientifically appropriate ▪ identify a source of error in a measurement or a flaw in an experimental design.

At Level 1b students can be required to:

- determine which variables were changed, measured, or held constant when provided with a description of a scientific investigation
- identify the appropriate instrument or units to measure a quantity from a selection of different instruments or units.

At Level 1a students can be required to:

- identify the question that is being answered in a simple scientific investigation in which only one factor is varied at a time; for instance, by describing a study and then asking the student to explain what question is being answered
- identify which of several actions it might be best to undertake to answer a simple scientific question. For instance, the question "Where do woodlice live?" is best answered by pattern seeking, identification using criteria or fair testing.
- propose specific measurements that might be needed to answer a simple scientific question. For instance, a question might ask which of several variables should be measured to investigate whether the length of a pendulum affects the time of swing. Alternatively, a question might ask which of several variables should be controlled when conducting a simple investigation.
- from a list of several actions, identify which actions would reduce the error in an experiment. Such questions should be assessed using partial credit scoring.
- identify a variable (dependent and independent variables and controlled variable) in a simple scientific enquiry that should be controlled or should be varied to answer a given question.
- identify a simple flaw in an experimental design, e.g. a failure to control variables, taking a single measurement or measuring the wrong factor.

However, the following requirements would be considered too advanced and beyond the scope of a Level 1 competency; students would only be expected to attain partial credit on an item. Thus, competency at this level would not require students to:

- evaluate multiple ways of exploring a given question scientifically
- evaluate multiple ways that are proposed to ensure the reliability of data in an investigation
- explain why some data might be anomalous
- given a phenomenon, generate questions for investigation.

Table 4.1 Desired distribution of science items, by competency

Competency	Percentage of items in PISA 2015	Percentage of items in PISA-D
Explain phenomena scientifically	40-50	40-50
Interpret data and evidence scientifically	30-40	30-40
Evaluate and design scientific enquiry	20-30	20-30

The desired distribution specifies the blueprint for selecting items according to important aspects of the domain frameworks. Item selection is based on the assessment design as well as item characteristics related to a number of framework aspects, including competency, content, type of knowledge and response formats, as well as consideration of the items' psychometric properties and appropriateness for this assessment. Following the assessment, the actual distributions of items across the framework aspects will be described in relation to the desired distributions. The extent to which the item pool for the assessment meets the framework specifications will be discussed in the technical report in the context of practical constraints in the item selection process.

Scientific knowledge

Content knowledge

Given that only a sample of the content domain of science can be assessed in the PISA 2015 and PISA-D scientific literacy assessments, 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 4.5 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.

Figure 4.5 ■ **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)

Source: OECD (2016a), *PISA 2015 Assessment and Analytical Framework*, http://dx.doi.org/10.1787/9789264255425-en.

Table 4.2 shows the desired distribution of items, by content of science, for PISA 2015 and PISA-D.

Table 4.2 Desired distribution of science items, by content

System	Percentage of items in PISA 2015	Percentage of items in PISA-D
Physical	36	36
Living	36	36
Earth and space	28	28
Total	100	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 4.6 convey the general features of procedural knowledge that may be tested.

Figure 4.6 ▪ **PISA 2015 and PISA-D 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, 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 4.7 represents what are considered to be the major features of epistemic knowledge necessary for scientific literacy.

Figure 4.7 ▪ **PISA 2015 and PISA-D 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 4.7. 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 4.3 describes the desired distribution of items by type of knowledge for PISA 2015 and PISA-D.

Table 4.3 Desired distribution of science items, by type of knowledge

Knowledge	Percentage of items in PISA 2015	Percentage of items in PISA-D
Content	54-66	54-66
Procedural	19-31	19-31
Epistemic	10-22	10-22

The desired balance, by percentage of items, among the three knowledge components – content, procedural and epistemic – for PISA 2015 and PISA-D is shown in Table 4.4.[1]

Table 4.4 Desired distribution of science items for knowledge

Knowledge types	Percentage of items in PISA 2015	Percentage of items in PISA-D
	Total over systems (physical, living, earth and space)	
Content	54-66	54-66
Procedural	19- 31	19- 31
Epistemic	10-22	10-22
Total over knowledge types	100	100

ASSESSING SCIENTIFIC LITERACY

Cognitive demand

A key new feature of the PISA 2015 framework that will also be used in PISA-D 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 and PISA-D Frameworks. 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 4.8 ▪ **PISA 2015 and PISA-D Framework for Cognitive Demand**

		Competencies			Depth of Knowledge		
		Explain phenomena scientifically	Evaluate and design scientific enquiry	Interpret data and evidence scientifically	Low	Medium	High
Knowledge	Content knowledge						
	Procedural knowledge						
	Epistemic knowledge						

The grid in Figure 4.8 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.

Table 4.5 shows the real distribution of items by depth of knowledge for PISA 2015 (there was no desired distribution specified for the depth of knowledge categories). Since the PISA-D assessment design calls for a greater proportion of items measuring the lower end of the scale, this criterion will presumably affect the distribution of items across the three categories of depth of knowledge. Compared to the distribution of items in the PISA 2015 assessment, there will likely be a greater proportion of items classified as "low" or "medium" depth of knowledge than in the "high" category in the PISA-D assessment.

Table 4.5 Distribution of science items, by depth of knowledge

Depth of knowledge	Percentage of items in PISA 2015	Percentage of items in PISA-D
Low	8	Not yet available
Medium	30	Not yet available
High	61	Not yet available
Total	100	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:

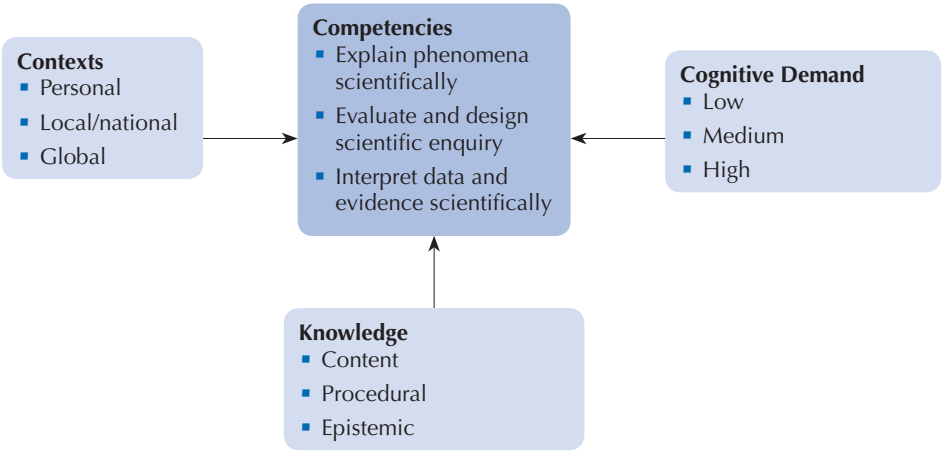
- The number and degree of complexity of elements of knowledge demanded by the item.
- The level of familiarity and prior knowledge that students may have of the content, procedural and epistemic knowledge involved.
- The cognitive operation required by the item, e.g. recall, analysis, evaluation.
- 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 4.10).

Test characteristics

Figure 4.9 is a variation of Figure 4.2 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 4.9 ▪ **A tool for constructing and analysing assessment units and items**



Source: OECD (2016a), *PISA 2015 Assessment and Analytical Framework*, http://dx.doi.org/10.1787/9789264255425-en.

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).

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 are limited. Questions within the domain of science that assess reading or mathematical literacy are avoided.

In PISA-D, for a better measurement of items at proficiency Levels 1 and 2, items should only make the lower-level cognitive demands of recalling or recognising appropriate knowledge, understanding the meaning of texts, applying that knowledge, and very simple data analysis drawing on either factual knowledge or foundational concepts (Anderson and Krathwohl, 2001; Webb, 1997). In addition, whatever proficiency level they measure, items and language should wherever possible be simplified to reduce the cognitive load demanded of students (Sweller, 1994).

Response formats

Three classes of items will be 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 in PISA 2015 and PISA-D:

- 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.
- 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 items is supported by simple drawing editors that are specific to the response required.

Reporting proficiency in science in PISA-D

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). 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 scales for the 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 4.10. For PISA-D, the table describing the performance level expectations has been extended to include a new Level 1c.

The proposed level descriptors are based on the *PISA 2015 Results Volume I* (OECD, 2016b) and offer a qualitative description of the differences between levels of performance. Proficiency Levels 2, 1a and 1b were modified to implement a clear line of progression in knowledge from 1c. 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.

Figure 4.10 ▪ **Summary description of the eight levels of science proficiency in PISA-D**

Level	Lower score limit	Percentage of students across OECD countries at each level, PISA 2015	Percentage of students across 23 middle- and low-income countries at each level, PISA 2015	Descriptor
6	708	1.1%	0.1%	At Level 6, students can draw on a range of inter-related scientific ideas and concepts from the physical, life and earth and space sciences and use content, procedural and epistemic knowledge in order to offer explanatory hypotheses of novel scientific phenomena, events and processes or to make predictions. In interpreting data and evidence, they are able to discriminate between relevant and irrelevant information and can draw on knowledge external to the normal school curriculum. They can distinguish between arguments that are based on scientific evidence and theory and those based on other considerations. Level 6 students can evaluate competing designs of complex experiments, field studies or simulations and justify their choices.
5	633	6.7%	0.8%	At Level 5, students can use abstract scientific ideas or concepts to explain unfamiliar and more complex phenomena, events and processes involving multiple causal links. They are able to apply more sophisticated epistemic knowledge to evaluate alternative experimental designs and justify their choices and use theoretical knowledge to interpret information or make predictions. Level 5 students can evaluate ways of exploring a given question scientifically and identify limitations in interpretations of data sets including sources and the effects of uncertainty in scientific data.
4	559	19.0%	5.0%	At Level 4, students can use more complex or more abstract content knowledge, which is either provided or recalled, to construct explanations of more complex or less familiar events and processes. They can conduct experiments involving two or more independent variables in a constrained context. They are able to justify an experimental design, drawing on elements of procedural and epistemic knowledge. Level 4 students can interpret data drawn from a moderately complex data set or less familiar context, draw appropriate conclusions that go beyond the data and provide justifications for their choices.
3	484	27.2%	15.5%	At Level 3, students can draw upon moderately complex content knowledge to identify or construct explanations of familiar phenomena. In less familiar or more complex situations, they can construct explanations with relevant cueing or support. They can draw on elements of procedural or epistemic knowledge to carry out a simple experiment in a constrained context. Level 3 students are able to distinguish between scientific and non-scientific issues and identify the evidence supporting a scientific claim.
2	410	24.8%	28.3%	At Level 2, students are able to draw on scientific content knowledge or procedural knowledge to identify an appropriate scientific explanation, interpret data, and identify the question being addressed in a simple experimental design. They can use basic or everyday scientific knowledge to identify a valid conclusion from a simple data set. Level 2 students demonstrate basic epistemic knowledge by being able to identify questions that could be investigated scientifically.

Figure 4.10 [continued] ■ **Summary description of the eight levels of science proficiency in PISA-D**

Level	Lower score limit	Percentage of students across OECD countries at each level, PISA 2015	Percentage of students across 23 middle- and low-income countries at each level, PISA 2015	Descriptor
1a	335	15.7%	31.5%	At Level 1a, students are able to draw on basic scientific content or procedural knowledge to recognise or identify explanations of simple scientific phenomenon presented using scientific language. With support, they can undertake structured scientific enquiries with no more than two variables. They are able to identify simple causal or correlational relationships and interpret graphical and visual data that require a low level of cognitive demand. Level 1a students can select the best scientific explanation for given data in familiar personal, local and global contexts. When presented with multiple factors of varying complexity requiring a low level of content knowledge or cognitive demand, students can select the best scientific explanations or procedures in a question in most but not all instances.
1b	260	4.9%	15.7%	At Level 1b, students can draw on everyday scientific knowledge to recognise aspects of familiar or simple phenomena presented using minimal scientific language. They are able to identify simple patterns in data, recognise basic scientific terms, identify the real-world features represented by simple models, and follow explicit instructions to carry out a scientific procedure.
1c	186	0.6% (percentage of students scoring below Level 1b, PISA 2015)	3.1% (percentage of students scoring below Level 1b, PISA 2015)	At Level 1c, students can recall an element of everyday scientific information or observations of common macroscopic phenomena to identify a correct scientific explanation or conclusion which has been communicated using non-technical or non-academic language and supported by illustrations.

Note: Descriptors 3 through 6 are the same as those used in PISA 2015, while descriptors 2,1a and 1b have been revised for a better progression in knowledge from 1c. While the description of Level 1c was added, it has not been populated with any items, so PISA-D will not report student results in this level. Level 1c and the progression in knowledge from 1c will be further developed in PISA 2024, when science will be the main domain.

Items at the newly created Level 1c should be familiar to students' everyday lives or draw on ideas that permeate contemporary culture. All items should, whenever possible, attempt to draw on macroscopic phenomena that students may have experienced or observed or learnt in the curriculum. Equally important is to have all items formulated in the simplest possible language. Sentences should be short and direct. Lengthy sentences, compound nouns and complex phrasing should be avoided. Vocabulary used in the items must be carefully examined to avoid the use of academic language and, wherever possible, simplify the scientific language. Wherever possible, the cognitive processing should only require one-step reasoning and use simple data or descriptions.

In order to enter Level 1c performance, a student must have the foundational skills required to:

- read and comprehend simple sentences
- use numeracy and basic computation
- understand the basic components of tables and graphs
- apply the basic procedures of scientific enquiry
- interpret simple data sets.

Testing scientific literacy in the out-of-school population

The scientific literacy domain is not included in the out-of-school PISA-D assessment due to practical reasons related with the instrument. On one hand, the total test allows a maximum of 50 minutes, which is not enough time to include an assessment of three domains, so it became necessary to choose only two. In deciding, it was taken into account that reading and mathematics literacy are considered as foundational skills and necessary for the development of scientific

literacy skills. In addition, the target population was also considered. Science is the domain with the strongest link to school, so the least appropriate for a group that by definition has been exposed to less formal schooling. Thus, it was decided that reading and mathematics were the only domains that should be included in the assessment for out-of-school 14-16 year-olds.

Examples of items for addressing the extended PISA-D science framework

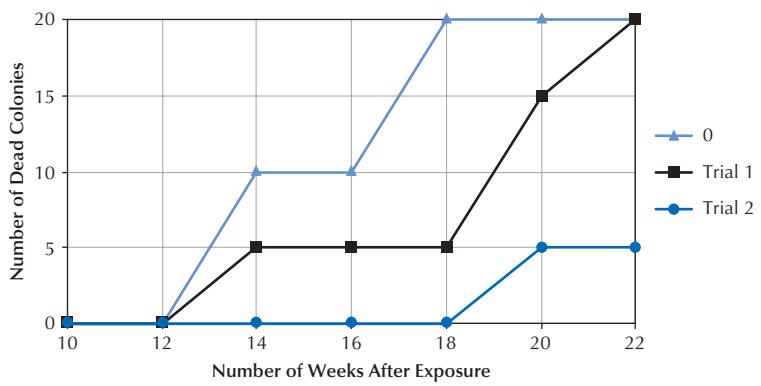
The following items illustrate the types of questions that can be asked of students at Level 1.

Sample item 1: Death of Bee Colonies – Level 1a

Scientists believe there are many causes why bee colonies die. One possibility is an insecticide that may cause bees to lose their sense of direction outside the hive.

Researchers tested whether this insecticide leads to the death of bee colonies. In a number of hives, they added the insecticide to the food of the bees for three weeks. All of the hives were given the same amount of food but the food had different amounts of insecticide in. Some hives were not given any insecticide.

None of the colonies died immediately. However, by week 14, some of the hives were empty. The following graph records the results:



What did the experiment test? Choose one of the responses below:

A. The experiment tested the effect of insecticide on the resistance of bees over time.

B. The experiment tested the effect of varying amounts of insecticide on the number of empty hives found over time.

C. The experiment tested the effect of the death of bee colonies on the resistance of bees to insecticide.

D. The experiment tested the effect of the death of bee colonies on the concentration of the insecticide.

Framework categories	2015 Framework extension
Competency	Evaluate and design scientific enquiry
Full description of competency	Students must identify a question being asked in a simple scientific enquiry where only one factor is being varied at a time
Knowledge	Evaluate and design scientific enquiry
Context	Local/national-environmental quality
Cognitive demand	Low
Item format	Multiple choice

Sample item 2: Fossil fuels – Level 1a

Many power plants burn fuel that gives off carbon dioxide. Adding more carbon dioxide into the air has a negative impact on the climate. There are different strategies to reduce the amount of carbon dioxide added to the air.

One such strategy is to burn biofuels instead of fossil fuels.

Another strategy involves trapping some of the carbon dioxide emitted by power plants and storing it deep underground or in the ocean. This strategy is called carbon capture.

Using biofuels does not have the same effect on levels of carbon dioxide in the air as using fossil fuels. Which of the statements below best explains why?

A. Biofuels do not release carbon dioxide when they burn.

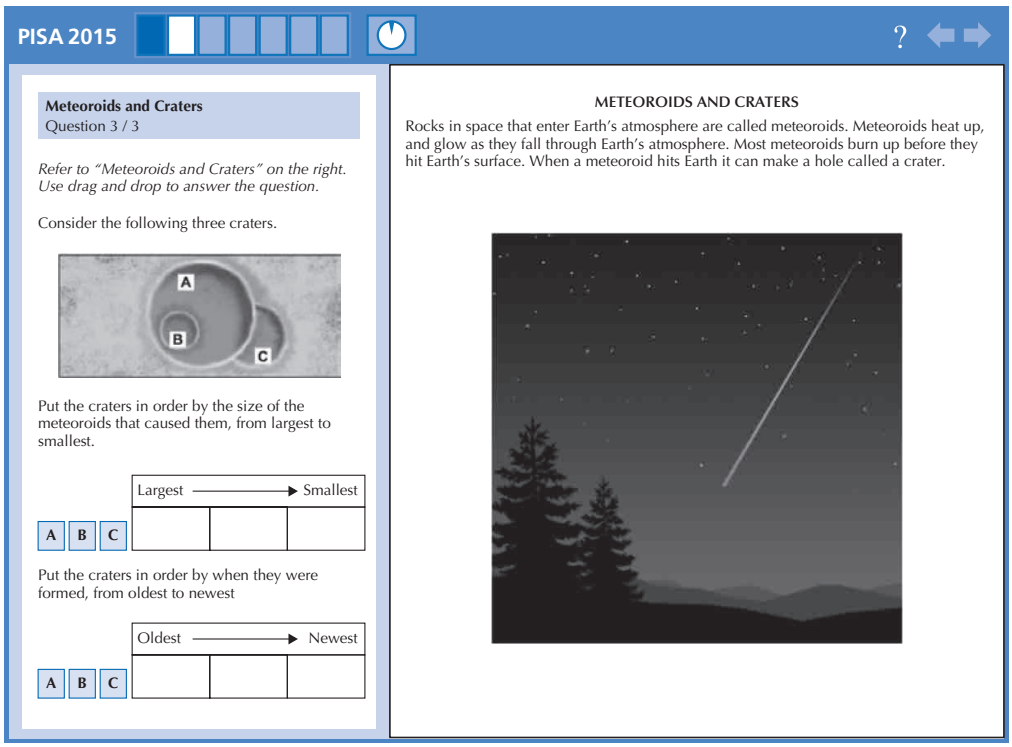
B. Plants used for biofuels absorb carbon dioxide from the air as they grow.

C. As they burn, biofuels take in carbon dioxide from the air.

D. The carbon dioxide released by power plants using biofuels has different chemical properties than that released by power plants using fossil fuels.

Framework categories	2015 Framework extension
Competency	Explain phenomena scientifically
Full description of competency	Identify scientific concept appropriate to explain a phenomenon
Knowledge	Physical sciences
Context	Global/Natural resources
Cognitive demand	Low
Item format	Multiple choice

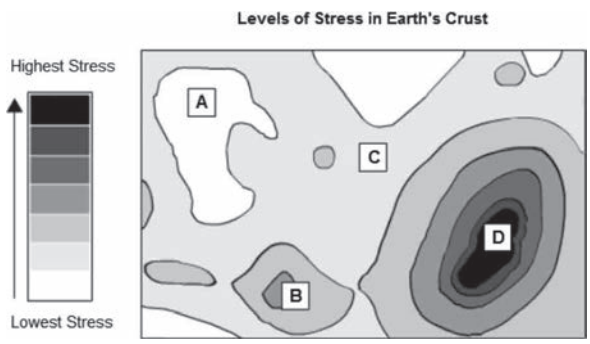
Sample item 3: Meteoroids and craters – Level 1b



Framework categories	2015 Framework extension
Competency	Interpret data and evidence scientifically
Full description of competency	Given a simple set of observations, draw a correct inference
Knowledge	Earth and space sciences
Context	Global
Cognitive demand	Low
Item format	Multiple choice

Sample item 4: Groundwater extraction and earthquakes – Level 1b

GROUNDWATER EXTRACTION AND EARTHQUAKES
Stress in Earth's Crust



The map above shows the levels of stress in Earth's crust in a region. Four locations within the region are identified as A, B, C, and D. Each location is on or near a fault that runs through the region.

Which of the following correctly rank risk of earthquake from lowest to highest? Choose one of the answers below:

A. D, B, A, C

B. A, C, B, D

C. D, B, C, A

D. A, D, C, B

Framework categories	2015 Framework extension
Competency	Interpret data and evidence scientifically
Full description of competency	Given a simple chart, identify which conclusion is correct
Knowledge	Procedural
Context	Local/National hazards
Cognitive demand	Low
Item format	Multiple choice

Notes

1. Because science was the main domain in PISA 2015 this was reported separately for the three systems (physical, living, and earth and space). Since there are no subscales reported for PISA-D, the desired distribution for knowledge types is the total over all systems.

References

AAAS (1989), *Science for all Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics and Technology*, American Association for the Advancement of Science, 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, London.

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

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

Bloom, B. S. (ed.) (1956), *Taxonomy of Educational Objectives: The Classification of Educational Goals Handbook 1, Cognitive Domain*, Longmans, London.

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*, Information Age Publishing, Charlotte, NC.

COSCE (2011), *Informe ENCIENDE. Enseñanza de las Ciencias en la Didáctica Escolar para Edades Tempranas en España*, (ENCIENDE Report: Teaching Science to Early Years in Schools in Spain), Confederacion de Sociedades Cientificas de España, Madrid, www.cosce.org/pdf/Informe_ENCIENDE.pdf.

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,* Information Age Publishing, Charlotte, NC.

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, Taylor and Francis Group, London, 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, SAGE Publications, Thousand Oaks, CA, pp. 268-291.

EC (1995), *White Paper on Education and Training: Teaching and Learning – Towards the Learning Society*, Office for Official Publications in European Countries, Luxembourg, http://aei.pitt.edu/1132/.

Fensham, P. (1985), "Science for all: A reflective essay", *Journal of Curriculum Studies*, Vol. 17/4, Taylor and Francis Group, London, pp. 415-435.

Ford, M. J. and B.M. Wargo (2012), "Dialogic framing of scientific content for conceptual and epistemic understanding", *Science Education*, Vol. 96/3, Wiley, Hoboken, NJ, pp. 369-391.

Gardner, P. L. (1975), "Attitudes to science", *Studies in Science Education*, Vol. 2, Taylor and Francis Group, London, pp. 1-41.

Gott, R. et al. (2008), *Research into Understanding Scientific Evidence*, University of Durham, Durham, www.dur.ac.uk/rosalyn.roberts/Evidence/cofev.htm.

Kane, M. (2006), "Validation", in R L. Brennan (ed.), *Educational Measurement*, 4th ed., American Council on Education, Praeger Publishers, Westport, CT.

Klopfer, L. E. (1976), "A structure for the affective domain in relation to science education", *Science Education*, Vol. 60/3, Wiley, Hoboken, NJ, pp. 299-312.

KMK (2005), *Bildungsstandards im Fach Biologie für den Mittleren Schulabschluss (Jahrgangsstufe 10)*, (Educational Standards in Biology for the Intermediate School Diploma [Year 10]), Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland, Berlin.

Kuhn, D. (2010), "Teaching and learning science as argument", *Science Education*, Vol. 94/5, Wiley, Hoboken, NJ, pp. 810-824.

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 Associates, Mahwah, NJ.

Longino, H. E. (1990), *Science as Social Knowledge*, Princeton University Press, Princeton, 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, Taylor and Francis Group, London, pp. 1499-1521.

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, Taylor and Francis Group, London, pp. 207-248.

Millar, R. and J.F. Osborne (eds.) (1998), *Beyond 2000: Science Education for the Future*, King's College, London.

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

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

National Research Council (2000), *Inquiry and the 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.

OECD (2016a), *PISA 2015 Assessment and Analytical Framework: Science, Reading, Mathematic and Financial Literacy*, PISA, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264255425-en.

OECD (2016b), *PISA 2015 Results (Volume I): Excellence and Equity in Education*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264266490-en.

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

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

OECD (2006), *The PISA 2006 Assessment Framework for Science, Reading and Mathematics*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264026407-en.

OECD (2003), *The PISA 2003 Assessment Framework: Mathematics, Reading, Science and Problem Solving Knowledge and Skills*, 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*, 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.

Osborne, J.F. (2010), "Arguing to learn in science: The role of collaborative, critical discourse", *Science*, Vol. 328/5977, American Association for the Advancement of Science, Washington, DC, pp. 463-466.

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, Taylor and Francis Group, London, pp. 1049-1079.

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

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

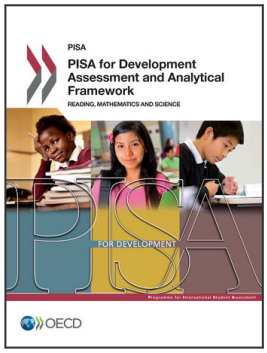
Sweller, J. (1994), "Cognitive load theory, learning difficulty and instructional design", *Learning and Instruction*, Vol. 4 , pp. 295-312.

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, Nairobi, http://wedocs.unep.org/handle/20.500.11822/8056.

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, Washington, DC.

Ziman, J. (1979), *Reliable Knowledge*, Cambridge University Press, Cambridge, England.



From:

PISA for Development Assessment and Analytical Framework

Reading, Mathematics and Science

Access the complete publication at:

https://doi.org/10.1787/9789264305274-en

Please cite this chapter as:

OECD (2018), "PISA for Development Science Framework", in *PISA for Development Assessment and Analytical Framework: Reading, Mathematics and Science*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789264305274-6-en

This work is published under the responsibility of the Secretary-General of the OECD. The opinions expressed and arguments employed herein do not necessarily reflect the official views of OECD member countries.

This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

You can copy, download or print OECD content for your own use, and you can include excerpts from OECD publications, databases and multimedia products in your own documents, presentations, blogs, websites and teaching materials, provided that suitable acknowledgment of OECD as source and copyright owner is given. All requests for public or commercial use and translation rights should be submitted to rights@oecd.org. Requests for permission to photocopy portions of this material for public or commercial use shall be addressed directly to the Copyright Clearance Center (CCC) at info@copyright.com or the Centre français d'exploitation du droit de copie (CFC) at contact@cfcopies.com.