PISA 2025 SCIENCE FRAMEWORK (DRAFT)

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PISA 2025 Science Framework (Second Draft)

1. Introduction

1. The fundamental goal of PISA is to measure students' ability to use their knowledge. In short to demonstrate that their knowledge and understanding is demonstrated by their ability to manifest a particular set of competencies. The competencies developed by scientific education are perceived to be a key educational outcome (Rychen & Salganik, 2003) and defined in terms of the ability to use scientific knowledge and information interactively – that is 'the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen', and to use them for informed decision making. In this document, that outcome is framed in terms of three specific competencies which represent a major goal for science education for all students. Therefore, the view of scientific competencies which form the basis for the 2025 international assessment of 15-year-olds is a response to the question: What is important for young people to know, value, and be able to do in situations requiring the use of scientific and technological knowledge?

2. The goal of this document is to provide a description and rationale for the framework that forms the basis of the instrument to assess the outcomes of science education – the major domain for PISA 2025. Previous PISA frameworks for the science assessment (OECD, 1999, 2003, 2006, 2016) have elaborated a conception of scientific literacy as the central construct for science assessment. Within this document, the outcomes of scientific education are defined in terms of a set of three competencies that an individual would be expected to display. These competencies form the basis of the construct to be tested (Wiliam, 2010). The framework for PISA 2025 refines and extends the previous competencies by building on the PISA 2015 framework, and the thinking of the expert group convened to develop this framework.

2. Science & Why it Matters

3. Science education matters. At one level, there is the economic imperative faced by all OECD countries of ensuring that they educate the next generation of scientists. However, such a goal does not justify compulsory education in science for all students from kindergarten to age 15 or higher. Science earns its place at the curriculum table along with mathematics and literacy for two fundamental reasons. First, scientific knowledge represents a great cultural and intellectual achievement. In the space of a little over 400 years, our understanding of the living and non-living world has been totally transformed, improving our well-being and health in ways that were simply unimaginable then. Science has fundamentally changed our understanding of the universe we inhabit, the nature of the human body, the matter that surrounds us, how we came to be, the transmission of disease and its prevention and much, much more. Education is how this cultural achievement is shared with the next generation.

4. Somebody who has experienced an education in science should then have some sense of the intellectual achievement that the sciences represent. They should be able to identify the major scientific ideas that have had a transformative effect on our culture and explain why. In addition, they would be able to point to the transcendent nature of this knowledge and the phenomena that it can explain; to wonder at its possible beauty, and to recognise the intellectual creativity that imagined the world not as it appears to be, but as one which often defies commonsense (Wolpert, 1992). For example, the idea that day and night is caused by a spinning Earth rather than a moving Sun or the idea that you look like your parents because every cell in your body carries a chemically coded message to enable our replication.

5. Second, a knowledge and understanding of science, and the ways in which it generates reliable knowledge, is crucial for citizens who need to make informed personal decisions about science-related phenomena such as health and the environment to engage in action within their families, local communities and wider societies. This is particularly important in the 21st century when humanity faces an uncertain future as it enters the Anthropocene, an era in which human impact is significantly changing Earth's systems, and a knowledge of science then matters at the individual, regional and global levels as we seek to address these impacts.

6. For it is the science that informs us that life as we know it is in crisis, with climate change and biodiversity loss – arguably the greatest issues of our time -– impacting all species, many irrevocably, and precipitating the sixth mass extinction (Dirzo et al., 2014). The challenges we face as a population of 7 billion people with finite natural resources, are the need for clean water, food supply, managing and preventing disease, producing energy sustainably, and the many others resulting predominantly from human-generated climate change (IPCC, 2021). Dealing with all of these challenges will require a major contribution from science and technology, as well as other knowledge systems.

7. Education, and schools are essential for preparing youth to deal with these challenges by developing their agency in the Anthropocene era. Scientifically educated citizens and societies understand how to evaluate and judge the credibility of scientific information and expertise to inform their actions – actions that are needed to bring about change both at the local level, where individuals and institutions may be faced with decisions about practices that affect their own health and food supplies, and at the national level. Science education can also inform and contribute to developing an ethic of care and justice that recognises the interdependence of living things, and by enabling systems thinking and creativity to design effective strategies to bring about the change required.

8. At the personal level, too, individuals are faced with choices about how to act e.g. whether to adopt a vegetarian diet, whether to farm sustainably, or whether to get vaccinated, and many more. All of this requires a citizenry capable of evaluating the information, experts, and other voices. And, as argued by the European Commission, the solutions to political and ethical dilemmas involving science and technology 'cannot be the subject of informed debate unless young people possess certain scientific awareness' (European Commission, 1995, p. 28). Moreover, while 'this does not mean turning everyone into a scientific expert' it does mean providing them with a science education that would 'enable 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). This means understanding some of the social norms and practices science has established to ensure the knowledge it offers is trustworthy such as the importance of scientific consensus, the markers of expertise, the limits to certainty and the mechanisms that the sciences have developed for avoiding error.

9. The explosion of information online has made the competency to critically evaluate scientific reports in the media and social networks ever more important, particularly when science is central to so many of these issues. And particularly when 85% of adolescents indicate that they use Google, 2/3 use YouTube, and about half use Wikipedia. Today at least a quarter of young people receive news and up-to-date information via social media or online news sources. New technologies accelerate and amplify communication, both of information and disinformation. As a result, false news can travel faster, farther, and more broadly on Twitter than true accounts (Vosoughi et al., 2018). One unfortunate consequence is that scientific information has become politicised and challenged by those who either claim scientific credentials or by those who seek to deny its validity (Oreskes and Conway, 2010, Michaels, 2020).

10. Thus, a specific goal of science education has to be to develop the competency to "research, evaluate and use scientific information for decision making and action". This competency can only be developed by explicit teaching of some of the epistemic features and social practices that sustain the practice of science. For instance, this competency requires an understanding of why and when to trust science (Oreskes, 2019). Today we live in a society where we are all epistemically dependent on expertise (Hardwig, 1985, Norris, 1997, Nichols, 2017, Lynch, 2016). Commonly we are faced with decisions about whether to purchase an electric car, avoid eating meat, or install solar panels. Non-experts simply lack the depth of knowledge needed to make an independent judgement (Hardwig, 1985). Thus, the challenge that we are confronted with is evaluating expertise in a sea of misinformation or worse – disinformation. Bergstrom and West put it more bluntly arguing that it requires the competency to identify and challenge "bullshit" (Bergstrom and West, 2020). In the case of scientific information, fundamental to this competency is the knowledge that confidence in science is built by the emergence of a consensus among scientists. And, while the process of science is not infallible, and the history of the sciences can be seen as a history of error (Allchin, 2012), science, as an institution and practice, has well established mechanisms for vetting scientific claims and identifying mistakes, all of which help to establish trust and confidence in the knowledge it offers.

11. In addition, an education in science requires not just a knowledge of the concepts and theories of science, but also a knowledge of the common procedures and practices associated with scientific enquiry, and how these enable science to advance. Therefore, individuals who are scientifically educated have a knowledge of the major concepts and ideas that form the foundation of scientific and technological thought; how such knowledge has been derived; the common practices undertaken by scientists; the degree to

which such knowledge is justified by evidence or theoretical explanations; and importantly, the social structures which enable the production of trustworthy knowledge.

12. Put simply, an *a priori* question of any scientific report is to ask whether there is any scientific consensus on this matter, and then whether it has been peer-reviewed. And, if the science is contested, what is the expertise and evidence of those who would contest the findings? Do they, for instance, have a conflict of interest? In short, to ask why critics should be trusted over the existing consensus. Thus, in the arguments around vaccination, we would expect scientifically educated students to ask: "What is the scientific consensus about vaccination?", "What is the nature of the evidence on which that consensus is based?", "What is the scientific expertise of those who question the consensus?", "What is the nature of the evidence that is used for the critique?" Judgements of expertise require a knowledge of the mechanisms that society uses for validating expertise – that is "What qualifications does this individual have?", "Which institutions do they work for?", "What is their reputation in the field?" While personal decisions may involve issues of values and other beliefs it is still important to know and understand the relevant science.

13. In addition, a science education should be both broad and applied. Thus, the framework refers to a knowledge of science, science-based technology, and scientific and engineering practices. It should be noted, however, that science and technology do differ in their purposes, processes, and products. Technology asks: "What can we do with this knowledge?" seeking the optimal solution to a human problem where there may be more than one optimal solution. In contrast, science seeks to answer three questions about the natural material world: (1) What exists? (2) Why does any given phenomenon happen? and (3) How do we know?

14. Nevertheless, science and technology are closely related. For instance, new scientific knowledge enables new technologies such as the advances in material science that led to the development of better batteries, solar panels, lighter airplanes and more. Likewise, new technologies can lead to new scientific knowledge through the development, for instance, of better telescopes, microscopes, and digital instruments. Young people should also be able to recognise that, whilst science and technology are often a source of solutions, paradoxically, they can also be seen as a source of risk, generating new problems which, in turn, may require science and technology to resolve e.g. the disposal of the batteries from electric cars or the extraction of cobalt required for their batteries and its environmental consequences. Therefore, individuals need to be able to consider the implications of the application of scientific knowledge and the issues it might pose for themselves or the wider society.

15. Undoubtedly, many of the challenges of the 21st Century will require innovative solutions that have a basis in scientific thinking and scientific discovery. The recent development of novel mRNA vaccines and their potential for treating other diseases such as cancer is one such example. Another is the challenge of developing more efficient renewable energy supplies including new technologies such as hydrogen. Societies will therefore require a cadre of well-educated individuals to undertake the research and technological innovation that will be essential to meet the economic, social and environmental challenges which the world currently faces. Yet, to engage with the wider society, such scientists will also need to be both knowledgeable about science and technology – and hold a deep understanding of the workings of the scientific community, its limitations, and the consequences of its application.

3. The Outcomes of Science Education for 15-year-olds

16. Current thinking about the desired outcomes of science education is rooted strongly in the belief that an understanding of science is so important that it should be a feature of every young person's education e.g. American Association for the Advancement of Science, 1989; Confederacion de Sociedades Cientificas de España, 2011; Millar & Osborne, 1998; National Research Council, 2012; Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland (KMK), 2005 a-c; Taiwan Ministry of Education, 1999; Ministry of Education, China, 2017 a-c. Indeed, in many countries, science is an obligatory element of the school curriculum from kindergarten until the completion of compulsory education.

17. Many of the documents and policy statements cited above give pre-eminence to an education for citizenship. However, internationally, many of the curricula for school science are based on a view that the primary goal of science education should be the preparation of the next generation of scientists (Millar & Osborne, 1998, Osborne & Dillon, 2008). 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 become scientists, have led to an emphasis on teaching science through enquiry (National Academy of Science, 1995; National Research Council, 2000), new curriculum models (Millar, 2006) and more recently an emphasis on developing competency with a set of eight scientific practices (National Research Council, 2012) that address the needs of both groups. The emphasis in these frameworks and their associated curricula lies not on educating individuals to be producers of scientific knowledge. Rather, it is on educating young people to become informed critical users of scientific knowledge – a competency that all individuals are expected to need during their lifetimes (Directorate-General for Research and Innovation [European Commission], 2020).

18. To understand and engage in critical discussion, decision making and action about issues that involve science and technology requires three domain-specific competencies. The first is the competency to provide explanatory accounts of natural phenomena, technical artefacts and technologies and their implications for society. Such a competency requires a knowledge of the major explanatory ideas of science, the use of models, the questions that frame the practices and goals of science, and the social and ecological contexts in which science operates. The second is the competency to construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically: that is the ability to consider whether a research design is fit for purpose, how it might be improved, and whether appropriate procedures have been used coupled with the competency to interpret and evaluate data and evidence scientifically and evaluate whether the conclusions are warranted. The third is the competency to find and critically evaluate scientific information – and then use such knowledge for decision making that informs action.

19. Thus, the outcomes of science education for 15-year-olds in PISA 2025 are defined by the three competencies in Box 1.

Box 1. The Science Competencies

Science Competencies: The PISA 2025 Definition

A scientifically educated person can engage in reasoned discourse about science, sustainability and technology to inform action. This requires the competencies to:

1. **Explain phenomena scientifically:**

   Recognise, construct, apply and evaluate explanations for a range of natural and technological phenomena.

2. **Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically:**

   Appraise and evaluate ways of investigating questions scientifically, and interpret and evaluate scientific data critically.

3. **Research, evaluate and use scientific information for decision making and action:**

   Obtain scientific information on a specific global, local or personal science-related issue and evaluate its credibility, potential flaws and the implications for personal and communal decisions.

20. All these competencies require knowledge (Box 2). Explaining phenomena scientifically, for instance, demands a knowledge of the content of science – referred to hereinafter as content knowledge – and, in addition, the nature of scientific explanations and the evidence supporting them. The second and third competencies require more than a knowledge of what we know. Rather, they depend on an understanding of how scientific knowledge is established and the degree of confidence with which it is held. Specific calls, therefore, have been made for teaching 'the nature of science' (Lederman, 2006), 'ideas about science' (Millar & Osborne, 1998) or more recently 'scientific practices' (National Research Council, 2012). Recognising and identifying the features that characterise scientific enquiry requires a knowledge of the standard procedures that are the foundation of the diverse methods and practices used to establish scientific knowledge – referred to here as 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, the meaning of foundational terms such as theory, hypothesis and data, the importance of consensus, a knowledge of how to judge the proficiency of experts, the ways in which scientific information may be inappropriately used and presented, and how relevant scientific knowledge is in contributing to developing an answer or solution.

21. In addition to content knowledge, both procedural and epistemic knowledge are necessary to: identify questions that are amenable to scientific enquiry; judge whether appropriate procedures have been used to ensure that the claims are justified; and to distinguish the significance of scientific claims and evidence, matters of values, or economic considerations. Of significance in developing this definition of the outcomes of scientific education is that, in their lifetimes, individuals will need to acquire knowledge, not through scientific investigations, but by using resources such as libraries and the Internet. Procedural, epistemic and content knowledge are essential to deciding

whether the many claims to knowledge that pervade scientific reports and contemporary media have been derived using appropriate procedures and are warranted.

Box 2: Scientific Knowledge

Scientific Knowledge: PISA 2025 Definition

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

Knowledge of the procedures that scientists use to establish scientific knowledge is referred to as "**procedural knowledge**". This is a knowledge of the practices and concepts on which empirical enquiry is based such as repeating measurements to minimise error and reduce uncertainty, the control of variables, and standard procedures for representing and communicating data (Millar, Lubben, Gott, & Duggan, 1995). These have been elaborated as a set of "concepts of evidence" (Gott, Duggan, & 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, the values and issues that frame a question and drive scientific enquiry, a recognition of the variety of forms of scientific enquiry, and the role peer review and scientific consensus 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 Boxes 6, 7 & 8.

22. People need all three forms of scientific knowledge to perform all three competencies which are the focus of this framework. Therefore PISA 2025 will focus on assessing the extent to which 15-year-olds can display these competencies appropriately within a range of personal, local, national, and global contexts. This perspective differs from that of many school science programmes, which are often dominated by content knowledge. Instead, the framework is based on a broader view of the kind of knowledge of science required by participating members of contemporary society.

23. In addition, the competency-based perspective also recognises that there is an affective element to a student's display of these competencies – meaning that their sense of scientific identity, attitudes or disposition towards science will determine their level of interest, sustain their engagement, and will motivate them to take action (Osborne, Simon and Collins, 2003; Moote, Archer et al., 2020).

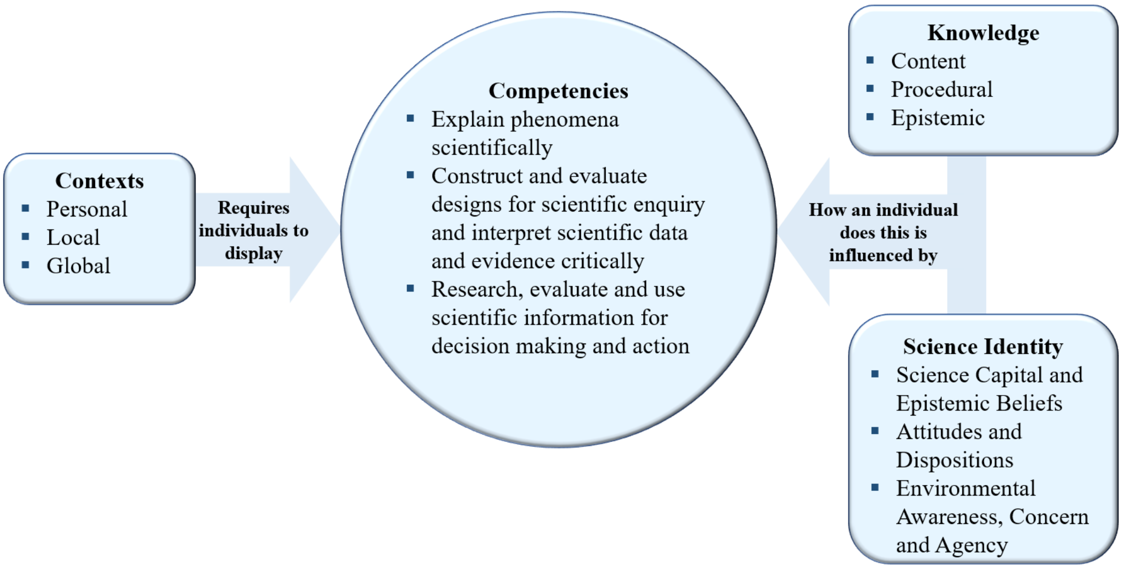
24. Furthermore, a science education should develop the competencies that enable a student to act should they so choose. Actions could be at the individual or household level, such as engaging in conservation behaviours or choosing to purchase or avoid products according to value-based criteria. Actions could also be taken with others to raise awareness within the community or make suggestions about solutions to environmental

problems. Being willing to take these actions requires knowledge but also hope and a vision that solutions are possible, as well as efficacy – both individual and collective – a belief that they can engage in these solutions.

25. Thus, the scientifically educated person would commonly have an interest in scientific and environmental topics; engage with the issues posed by science, health, technology, and sustainability; and feel that science has a meaningful connection and relevance to their life. Most of these individuals will not be employed as practising scientists. 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 and multiple areas of life. Such attitudes and dispositions are assessed through a separate 'non-cognitive' questionnaire.

26. Figure 1 summarises the outcomes of science education and their interrelationships.

Figure 1. Framework for PISA 2025 science assessment



Explanatory Notes

27. The following remarks are offered to clarify the meaning of what it means to be a scientifically and environmentally educated person at the age of 15 for the purposes of the PISA 2025 assessment.

a. The PISA science assessment places emphasis on the application of scientific knowledge in the context of everyday life situations.

b. For the purposes of the PISA assessment, it should be noted that these competencies will only be tested using the knowledge that 15-year-old students can reasonably be expected to have of the concepts and ideas of science (**content knowledge**), the procedures and strategies used in all forms of scientific enquiry (**procedural knowledge**), and the manner in which ideas are justified and warranted in science (**epistemic knowledge**).

c. Finally, throughout this document, the term 'natural world' is used to refer to phenomena associated with any object (living or non-living) or phenomenon occurring in the material world.

d. Within this document, science is used as a generic term to refer to any or all of the natural sciences: physics, chemistry, biology, Earth, space, and environmental sciences. The term technology is used in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems. As such it includes all types of human-made systems and processes and not just the limited sense that often equates technology with modern computational and communications devices. Technologies result when engineers apply their understanding of the natural world and of human behaviour to design ways to satisfy human needs and wants. In some countries, notably the United States, the term 'engineering' is used as a synonym.

e. Knowledge of and competency in addressing scientific problems is not limited to the realm of science. In addition, economics, political science, sociology, psychology, and anthropology all play a role in crafting meaningful, appropriate, ethically just, and viable solutions. This assessment, however, focuses specifically on the scientific competencies that underpin those decisions.

f. Three terms are used in the environmental section – 'environmental', 'ecological' and 'socio-ecological'. While there is some overlap between the domains indicated by these terms, environmental science draws on all the sciences including ecology. Ecology has a more refined focus and seeks to understand the interconnections within and between ecosystems. The term 'socio-ecological' indicates a wider, systems perspective on the close coupling of human and natural systems in relation to environmental challenges/crises, such as the sustainable management of aquifers that provide water to rivers and lakes, agriculture, and urban communities (Young et al., 2006; Eisemmenger et al., 2020).

Science Competencies: A Rationale

28. In this section an elaboration of each of the three competencies is provided and why they are considered an essential element of the outcomes of any science education.

Competency 1: Explain Phenomena Scientifically

29. The cultural achievement of science is a set of explanatory theories that have transformed our understanding of the natural world, such as the idea that day and night is caused by a spinning 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 enabling such things as the prevention of disease and rapid human communication across the globe. The competency to explain phenomena that occur in the material world is thus dependent on a knowledge of these major explanatory ideas of science (Harlen, 2010).

30. Constructing explanations of scientific, technological, and environmental phenomena, however, requires more than the ability to recall and use theories, explanatory ideas, information, and facts (content knowledge). Offering a scientific explanation 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 procedures and practices 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).

31. The competency to explain phenomena requires the ability to draw on a range of constructs and unobservable entities, e.g. atoms, cells, chemical reactions and to move between what is observable and their representations or models drawing on evidence (Braaten & Windschitl, 2011). For instance, explanations may appeal to the theory of evolution to explain how new strains of a virus emerge, or explain differences in properties of elements using their position on the periodic table. Explanations are often causal in nature, connecting a phenomenon with a theory or model that has wide ranging explanatory power, such as the kinetic molecular model of gases, or Newton's laws. Explanations can be simple or can involve causal chains of argument. Explaining a rainbow for instance can be done simply by showing that droplets break light into its constituent colours, or complex, using principles of dispersion, total internal reflection and refraction, involving diagrams, to account for a rainbow's shape and position. In biology, principles of structure and function and adaptation are used to explain structures and behaviours, such as differences in species found in different local habitats.

32. When explanations are tentative or speculative, however, they must be argued for (Osborne and Patterson, 2011) using reasoning and be consistent with evidence (Berland & Reiser, 2008). Predictions and suggesting solutions require arguments to be made using theories, concepts, or evidence. For instance, predicting what objects will float in water requires an understanding of relative density. Such knowledge can then enable the design of solutions. Explaining the societal or personal implications of scientific knowledge is also an important aspect of scientific competency, for instance explaining the basis of strategies for controlling evaporation in water conservation practice.

33. Constructing explanations often involves model-based reasoning (Lehrer & Schauble, 2006) – using models which can never be complete representations of reality. The Bohr model of the atom, for instance, is not an accurate model of the atom, there is much more to inheritance and the expression of phenotypes than the insights offered by Mendelian genetics, the ideal gas laws are what they say they are – ideal. Such models work because they are 'true enough' (Elgin, 2017). Moreover, because models are representations, they must be constructed using diagrams, figures or mathematics (Tytler & Prain, 2018). How and what they represent must be explained and their limitations. Current electricity is often represented as being like the flow of water in a pipe. And, while this is useful for explaining the function of an ammeter which is the equivalent of a flowmeter, it is not so useful for explaining the way a light comes on instantly when a switch is pressed. Understanding the central nature of models in explanation and how they can be used to communicate explanations appropriately are therefore important outcomes of any scientific education. In addition, many explanations require an understanding of systems, the elements they consist of and their interactions e.g. climate change, water pollution, plastics, and their impact on ecosystems.

34. To do this, scientists have developed an ontological zoo of unfamiliar entities and concepts e.g. of electrons, genes, molecules, point charges, elements, compounds and concepts such as heat, current, acceleration and many, many more (Ogborn et al., 1996) – many of which are abstract. These are used with a range of styles of reasoning e.g. mathematical deduction, experimental exploration, hypothetical modelling, categorisation and classification, probabilistic and statistical thinking, and historical based evolutionary reasoning (Crombie, 1994) to construct explanatory models of the material world (Lehrer and Schauble, 2006) using three forms of argument – induction, deduction and abduction (inference to the best possible explanation).

Competency 2: Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically

35. A knowledge of science implies that students should understand the endeavour of scientific enquiry which is to generate trustworthy knowledge about the natural and human made world (Ziman, 1979; Longino, 1990; Oreskes 2019). Investigating the natural and material world can take many forms. There is the identification of the range and diversity of species, rocks, or substance - a process of categorization and classification. Controlled experiments studies where variables are identified and controlled enable the testing of well-defined hypotheses while simulations and modelling enable the testing of theoretical ideas against sets of observational data

36. Data obtained by observation and experiment serve two functions. On the one hand, they can generate questions about the nature of the patterns and observations leading to the development of models and explanatory hypotheses that enable predictions. On the other hand, experiments, and the data they provide, are essential to testing the validity of predictions made by new hypotheses and models.

37. Scientists rarely work in isolation and are members of research groups or teams that engage in extensive collaboration with colleagues both nationally and internationally. New knowledge claims are always perceived to be provisional and may be found to lack justification when subjected to critical review by peers. Peer review is a formal mechanism which the scientific community has established to ensure the objectivity of scientific knowledge (Longino, 1990). Hence scientists have a commitment to publish or report their findings and the methods used in obtaining the evidence. Doing so enables empirical studies, at least in principle, to be replicated and results confirmed or challenged.

38. Measurements, however, can never be absolutely precise. Rather, they are all subject to a degree of error. Much of the work of the experimental scientist is, therefore, devoted to the reduction of 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. Data then has to be analysed, selected and refined to find the underlying patterns. This requires a process of interpretation and evaluation comparing findings with predictions and assessing the probability of the outcome being a chance event or evaluating alternative explanations. Students, therefore, need to develop an understanding that no measurement can be absolutely accurate and that there are standard ways of minimising error e.g. repeating measurements, taking averages, eliminating outliers etc.

39. Uncertainty in the measurement means that our confidence in a finding is expressed in terms of the probability. Scientists treat every claim with some degree of tentativeness, whether 51% confidence (only just more likely to be true than false) or 99.99% confidence (highly likely to be true). Using this form of reasoning makes it possible for scientists, on the one hand, to be comfortable with uncertainty, and on the other hand, to change their position when new evidence emerges. Decision making invariably involves working with a degree of uncertainty. However, just because science cannot give us absolute certainty does not mean we do not trust the results. The degree of scientific consensus in the findings informs our potential actions e.g the scientific consensus on climate change (Oreskes, 2004). All individuals should recognise this representation of the confidence in findings as a source of science’s strength, recognising that there is always a finite possibility of the finding having occurred by chance. Large programs of research with consistent findings provide us with confidence that the findings are very unlikely to have occurred by chance. All of this draws on a **procedural knowledge**.

40. Assessing scientific evidence may require an understanding of the concept of a normal distribution and the difference between a mean and a median. Furthermore, that confidence is commonly expressed with the use of an error bar, and that within any population there will be variability and outliers. In addition, they should understand that the larger the sample, the less likely there is to be error. Using this knowledge, the scientifically educated individual should be able to make evaluative judgments of statistical data asking, for instance, what meaning can be attached to the outliers. Moreover, they should understand that the notion of significance in science is based on a conception that a given finding is not a random effect. 15-year-olds should, for instance, be able to explain why using outliers for an argument is flawed e.g. my granny lived to 98 and smoked 28 cigarettes a day.

41. Science has well established procedures such as the use of controls that are the foundations of a logical argument to establish a causal relation. 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. Good explanatory models are also the foundation of any convincing causal relationship. For instance, the correlation between latitude and skin cancer is explained by the effect of u-v on the cell. Double-blind trials are another means of establishing causality enabling scientists to claim that the results have neither been influenced by the subjects of the experiment, nor by the experimenter themselves. Such ideas are fundamental to science and all 15-year-olds should have met these ideas and explain how they are essential to justifying scientific findings.

42. However, not all science is done using such methods. Some scientists spend their whole lives working at a desk developing explanatory models, often mathematical. Other scientists such as taxonomists, ecologists and epidemiologists are engaged in the process of identifying underlying patterns and interactions in the natural world that warrant a search for an explanation. Astrophysicists, climate scientists and geologists cannot conduct experiments on the natural world. Instead, by gathering data through detailed observations, their science relies on arguments that are an inference to the best explanation (abduction) and examining a range of hypotheses and eliminating those which do not fit with the evidence. Knowing something about the diversity and range of methods in science is, therefore, essential for the informed citizen. The scientifically educated individual should also be able to distinguish between cause and correlation, e.g. the sale of ice cream and the incidence of shark deaths (both increase in the summer but are causally unrelated) versus the incidence of lung cancer and smoking (which are causally related).

43. Facility in this competency requires a knowledge of the common procedures and practices used in science (**procedural knowledge**), and the function of these procedures in justifying any claims advanced by science (**epistemic knowledge**). This competency also draws on **content knowledge** to identify appropriate questions, assess and interpret findings. 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 warranted. Second, individuals who have this knowledge should be able to evaluate, at least in broad terms, whether a scientific question has been investigated appropriately.

44. Interpreting scientific data is such a core activity of science that all students should have some rudimentary understanding of the process. Initially data interpretation begins with looking for patterns, constructing simple tables and graphical visualisations such as pie charts, bar graphs, scatterplots or Venn diagrams of the distribution of heights in a class, eye colour and hair colour or the number of different species found in the school playground. At the higher level, it requires the use of more complex data sets and the use

of the analytical tools offered by spreadsheets, more sophisticated data analysis tools designed for schools, statistical packages, basic computational models and algorithms.

45. Moreover, individuals are increasingly confronted with representations, often visual or graphical, of complex data sets which need to be read, interpreted, and evaluated. Through science education an individual should, therefore, develop a familiarity with common forms of representation of data e.g. linear versus non-linear scales and common flaws in data representations e.g. inappropriate scales expressed in simple language. They should be able to translate between simple written textual accounts, diagrams and graphical representation. This knowledge and understanding are 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 to increase clarity as well as to persuade. Any relationships or patterns must then be recognised using a knowledge of standard patterns.

46. All individuals need to understand more than the procedures that have been applied to obtain any data set. That is they need to be able to judge whether these procedures are appropriate, and whether the ensuing claims are justified (**epistemic knowledge**). For instance, many sets of data can be interpreted in multiple ways. Argumentation and critique, therefore, 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 amongst scientists is therefore normal rather than extraordinary. Indeed, it is a critical and sceptical disposition towards all empirical evidence that many would see as the hallmark of the professional scientist.

47. Fundamental to this competency is the understanding that it requires a set of scientific practices from asking an appropriate scientific question, using appropriate scientific ideas to design an appropriate experiment or field observation, analysing and interpreting data to engaging in argument and critique to evaluate the best interpretation of the data (Ford, 2008). The idea of science as a set of practices engaged in by a community has emerged from the work of historians, philosophers, psychologists, and sociologists over the past 40 years. Seeing science as a set of shared practices shows that theory development, reasoning, and testing are components of a larger ensemble of activities that includes networks of participants and institutions (Longino, 2002); specialised ways of talking and writing (Halliday and Martin, 1993; Lemke, 1990); the development of models to represent systems or phenomena (Nersessian, 2008); the making of predictive inferences (Crombie, 1994); and the construction of appropriate instrumentation enabling the testing of hypotheses by experiment or observation (Giere et al., 2006).

Competency 3: Research, evaluate and use scientific information for decision making and action

48. True knowledge is a collective good. Today the Internet provides access to a sea of knowledge that was simply unimaginable even 20 years ago. The common assumption is that this is a good thing, and, in one sense, that is true. The Internet offers us answers to questions about everything from how to fix our broken bicycle to our concerns about health issues. In addition, it has brought together isolated individuals to pursue their common interests.

49. Across the globe, however, there is increasing concern about the ease with which people accept beliefs claimed to be ‘scientific’ for which there is no substantive material evidence and for which there is good evidence to the contrary. Whether it is the idea that

the Earth is flat, that vaccines cause autism, or that climate change is a hoax, the willingness of individuals to accept irrational beliefs – irrational in the sense that there is either no evidence or dubious evidence to support them – is of grave concern. For while true knowledge is a collective good, flawed or fake knowledge is both an individual and collective danger. For instance, the idea that vaccines are harmful endangers not only the lives of those who hold this idea, but the whole community who depends on a high level of vaccination to ensure its health. Obtaining and evaluating scientific information requires not just an understanding of the concepts but knowledge about science.

50. Essential to this competency is a knowledge and understanding of how trustworthy scientific knowledge is produced and "how monied interests try to 'bend' science, present pseudoscience as science, portray reliable science as 'junk science,' or foster an image of uncertainty even where scientific experts have reached a solid consensus." (Höttecke & Allchin, 2020, p. 4). Such understanding requires and draws on epistemic knowledge of the social practices of science. First, the scientifically educated individual needs a basic understanding of the transformations that occur in the trajectory from laboratory to publication, or from "test tube to Youtube". Second, an individual should be aware that there is a tendency of all individuals to seek confirmation for their biases which go unchallenged. Hence, they may exist in a 'bubble' supported by news that reinforces the views and perceptions they already have. All scientific information should be approached with a policy of circumspection which seeks to ask first if there is a conflict of interest, whether there is an established scientific consensus and whether the source has relevant expertise. In short, the process of evaluation starts not by interrogating the findings, as most competent outsiders do not have sufficient knowledge to do this, but rather examines the credibility of the source, and any potential prejudices of the channel of communication used in reporting the findings. Has, for instance, the finding been reported by somebody who has professional expertise in the relevant domain of science? In the current context, media literacy, especially digital media literacy, has become essential for all students (Höttecke & Allchin, 2020; Kozyreva, Lewandosky & Hertwig, 2020; Bergstrom & West, 2020) – particularly when research shows students' ability to evaluate sources is weak (Breakstone et al., 2021).

51. At the core of this competency is an understanding that science is a communal enterprise and that science is not infallible. In many ways, error is the norm in science (Allchin, 2012). However, while individual scientists or teams might be mistaken, the community is more trustworthy, and its goal is closure which is attained when there is overwhelming consensus. Moreover, that consensus is a consensus of experts (Collins & Evans, 2007; Oreskes, 2004, 2019; Selinger & Crease, 2006) as illustrated by the IPCC report on climate change which synthesised the findings of scientific teams across the globe. Nor is science a democracy where one scientist's views are as valuable as another. The views that matter are from those who have relevant background knowledge, skills in interpreting particular results, and awareness of potential flaws in reasoning. Thus, a petition claiming that vaccines are dangerous is meaningless if the signatories are not scientific experts on vaccination.

52. The scientifically educated individual also needs to understand that the image of the lone scientist making "great" discoveries does not represent reality. Rather, science is a communal and collaborative exercise where scientists vet each other's ideas to identify flaws in their work e.g. peer review (epistemic knowledge). The production of knowledge is dependent on a dialectic between construction and critique and that disagreement is both normative and productive (Ford, 2008). The scientifically educated individual would understand why critique is essential to the construction of knowledge in science and why science-in-the-making, particularly when there is not a well-established consensus, will change and evolve. A good example is contemporary climate models which are constantly

evolving and improving to the point where there is an overwhelming consensus about the phenomena, increasing accuracy in their predictions and the identification of the human impact. Consequently, science-based recommendations change as more and better data are available. When forming a view on any scientific claim to inform their possible action, an informed citizen should begin by asking what is the scientific consensus, do those presenting the claims have appropriate scientific expertise and what data and evidence are they using to support their claims? Based on such information, they should then be able to critique arguments that are flawed e.g. that reducing speed limits from 50 to 30 km/hr will have little effect, or that the risks of vaccines outweigh their benefits. Thus, this competency draws extensively on epistemic knowledge.

53. In evaluating action, students need to know that all activities have risks associated with them. Decisions about action often have to be taken in the absence of complete scientific knowledge and that uncertainty is an inherent feature of science (procedural and epistemic knowledge). Science rarely offers certain knowledge. Hence most decisions require an evaluation of risk (Beck, 1992; Adam, Beck & van Loon, 2000). When faced with potentially serious irreversible threats e.g. deforestation in the Amazon, the use of nuclear power, the precautionary principle is a common criterion to apply. Risk statistics, also only measure fatalities and not injuries and the decision to take risks is different depending on whether it is an individual risk e.g. riding a bike, a population risk e.g. the threat posed by a virus or new disease, a systemic risk e.g. biodiversity loss, or a lifetime versus immediate risk e.g. smoking ten cigarettes today versus smoking ten cigarettes a day. In addition, most decisions of this nature have a normative and social dimension which must also be weighed.

54. Making judgments about personal and societal policy can often involve dealing with unresolved and contested knowledge where scientists are working in complex and sometimes shifting environments, and also involves balancing competing interests and values separate from the science. Assessing risk in these situations can be difficult, involving on balance judgements about the status of scientific knowledge in relation to other values and interests. For instance, currently it is suggested that electric cars will reduce our dependence on fossil fuels and reduce pollution. Yet, electric cars currently require the mining of rare earths and have environmental and social impacts which raise issues of social justice such as use of inhuman/exploitative practices to take advantage of local labour and their environment.

4. Organisation of the Domain

55. For purposes of assessment, the PISA 2025 definition of the outcomes of any science education may be characterised as consisting of four interrelated aspects (Table 1).

Table 1: The Components of Science Education

1. Contexts	Personal, local, national, and global issues, both current and historical, which demand some understanding of science and technology.
2. Knowledge	An understanding of the major facts, concepts and explanatory theories that form the basis of scientific knowledge. Such knowledge includes both knowledge of 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).
3. Competencies	The ability to explain phenomena scientifically, construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically, and research, evaluate and use scientific information for decision making.
4. Science Identity	A set of dispositions, agency, attitudes towards science and personal capital indicated by an interest in science and technology; valuing of scientific approaches to enquiry, where appropriate, and a perception and awareness of environmental issues.

56. Each of these aspects is discussed further below.

Contexts for Assessment Items

57. PISA 2025 will assess important scientific knowledge using contexts that raise issues and choices that are relevant to the science and environmental education of participating countries. Such contexts will not, however, be restricted to the common aspects of participants' national curricula. Rather, the assessment will require evidence of the successful use of the three science competencies in important situations reflecting personal, local, national, and global contexts.

58. Assessment items will not be limited to school science contexts. In the PISA 2025 science assessment, the focus of the items will be 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 and environmentally based topics may be used as a common context. Also, appropriate to some topics are historical contexts which may be used to assess students' understanding of the processes and practices that are involved in advancing scientific knowledge.

59. Table 2 lists the applications of science and technology, within personal, local, national, and global settings that are primarily used as the contexts for assessment items. The applications will be drawn from a wide variety of life situations and will be generally consistent with the areas of application for scientific literacy in the previous PISA frameworks. The contexts will also be 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 competency has particular value for individuals and communities in enhancing and sustaining quality of life, and in the development of public policy.

Table 2. Contexts for the PISA 2025 science assessment

	Personal	Local/National	Global
Health & Disease	Maintenance of health, accidents, nutrition, vaccination	Control of disease, social transmission, food choices, obesity, community health	Pandemics, food Security, healthy Lifestyles
Natural Resources	Personal consumption of materials, types of food, and energy. Consuming locally produced foods. Choosing non-dairy and vegetarian diets	Maintenance of human populations, quality of life, security, production and distribution of food, energy supply. Environmental impact of mining and resource extraction. Production of renewable energy	Renewable and non-renewable sources of energy, natural systems, population growth, sustainable use of species and land. Biodiversity and its value
Environmental Impacts & Climate Change	Sustainable practices of recycling and reduction of resource use.	Population distribution, waste management, environmental impact. Use of regenerative agriculture	Environmental sustainability, management of pollution and air quality, loss of soil/biomass. Mass extinction of species. Ocean Acidification
Hazards	Risk assessments of lifestyle choices.	Rapid changes [e.g. earthquakes, severe weather], slow and progressive changes [e.g. coastal erosion, sedimentation], risk assessment. Facial recognition	Threats posed by Climate change, impact of modern communication, energy and its production e.g. fracking, nuclear, gas
Contemporary Scientific and Technological Advances and Challenges	Scientific aspects of the use of new technologies e.g. gene editing, virtual reality and	New materials, devices and processes, genetic modifications, health technology, transport, use of artificial intelligence	Exploration of space, origin and structure of the Universe

60. The PISA science assessment, however, is not an assessment of contexts. Rather, it assesses competencies and knowledge in specific contexts. The selection of these contexts, however, will be chosen based on the knowledge and understanding that students are likely to have acquired by the age of fifteen.

61. Sensitivity to linguistic and cultural differences will be a priority in item development and selection, not only for the sake of the validity of the assessment, but also to respect these differences in participating countries. In developing any international test, it is not possible, however, to include the differences in traditional and local knowledge about natural phenomena that exist between participating countries. This is not to deny, however, the contribution such knowledge can make and has made to their respective cultures.

Science Competencies: Performance Outcomes

62. In this section, an elaborated description of what kinds of performance and capability might be expected for each competency is provided. The set of science competencies in Box 3 to 5 reflects a view that science is best seen as an ensemble of social and epistemic practices which 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 what a scientifically educated person should both understand and be capable of doing. Fluency with these competencies is, in part, what distinguishes the expert scientist from the novice. Whilst it would be unreasonable to expect a 15-year-old student to have the expertise of a scientist, a scientifically educated student can be expected to appreciate their role and significance and undertake an approximation of the practice described.

Box 3. PISA 2025 Science competency 1

Explain phenomena scientifically

Produce and evaluate explanations and solutions for a range of natural and technological phenomena and problems demonstrating the ability to:

1. Recall and apply appropriate scientific knowledge;
2. Use different forms of representations and translate between these forms;
3. Make and justify appropriate scientific predictions and solutions;
4. Identify, construct, and evaluate models;
5. Recognise and develop explanatory hypotheses of phenomena in the material world;
6. Explain the potential implications of scientific knowledge for society

63. 15-year-olds who can demonstrate the competency of explaining phenomena scientifically can recall the appropriate knowledge in a given situation and apply it to construct an explanation for the phenomenon of interest. Explanations in science require different forms of representations and students need to be able to use written text, diagrams, charts, and graphs. Explaining in science also extends to predicting what will happen and proposing solutions to science-related problems. For example, planning ways of mitigating the effects of future sea-level rises. A scientifically educated person should be expected to draw on standard scientific models to construct and/or evaluate representations to explain everyday phenomena such as why water evaporates faster on a warm day, how introducing a new organism might disrupt a habitat, and why gases are compressible but liquids are not and use these explanations to make predictions.

64. Scientific content knowledge can also be used to recognise or develop tentative explanatory hypotheses in contexts where there is a lack of knowledge or data. Finally, 15-year-olds should be able to explain the potential implications of scientific knowledge for society. For instance, knowledge of the behaviour of viruses and bacteria to inform good social policy to prevent transmission, or knowledge of chemical processes to inform more sustainable solutions e.g. developing long-lasting batteries.

Box 4. PISA 2025 Science competency 2

Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically

Construct and evaluate scientific investigations, ways of addressing questions scientifically and interpret the data demonstrating the ability to:

- Identify the question in a given scientific study;
- Propose an appropriate experimental design;
- Evaluate whether an experimental design is best suited to answer the question;
- Interpret data presented in different representations, draw appropriate conclusions from data and evaluate their relative merits.

65. The competency to "construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically" is reliant on the ability to discriminate questions that can appropriately be answered by scientific investigation from other types of questions that draw on different ways of knowing in the world. Evaluating questions also requires a judgement of the value of the outcome and their importance. For instance, the search for a malaria vaccine has been an on-going 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.

66. This competency requires both procedural and content knowledge of the key features of an experimental investigation and other forms of scientific enquiry. For example, in the case of an experimental investigation, what quantities could be measured, what variables could be changed, and which should be controlled. Then what action should be taken so that accurate and precise data can be collected. In the case of developing simulations to model a phenomenon e.g. climate change, the spread of a virus, or the effect of running on body temperature, the individual needs to be able to identify the relevant variables and evaluate their fit with empirical data. This competency also requires the ability to identify if an investigation is driven by an underlying theoretical premise or, alternatively, whether it seeks to determine identifiable patterns such as the work of an epidemiologist.

67. For this competency, the scientifically educated individual 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 from data represented in standard simple forms e.g. Coronavirus charts, air quality data, or population statistics. They should also be able to make judgements about the conclusions that might be drawn from such evidence and whether they are warranted, drawing on their knowledge about the inherent uncertainty in data and the ways it might be misrepresented, whether it fits with the scientific consensus and the credibility of the source. Those who possess this competency can interpret the meaning of scientific evidence and its implications for a specified audience in their own words, using diagrams or other representations as appropriate. This competency may require the use of basic mathematical tools to analyse or summarise data, and the ability to use standard methods to transform data to different representations.

68. This competency includes the ability to recognise how data sets can be transformed into different types of visual display and how to select an appropriate data representation to respond to a given question. This involves the ability to recognise how different forms of data display emphasise or hide different aspects of data patterns, for instance using logarithmic scales to perceive numbers ranging over many orders of magnitude (Harford, 2020, Bergstrom & West, 2020) Such knowledge is fundamental to data literacy and the data representations commonly encountered both online and in the media.

Box 5. PISA 2025 Science competency 3

Research, evaluate and use scientific information for decision making and action

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

- Search, evaluate and communicate the relative merits of different sources of information (scientific, social, economic and ethical) that may have significance or merit in arriving at decisions on science-related issues, and whether they support an argument or a solution;
- Distinguish among claims based on strong scientific evidence, expert vs. non-expert, and opinion, and provide reasons for the distinction;
- Construct an argument to support an appropriate scientific conclusion from a set of data;
- Critique standard flaws in science-related arguments using epistemic and procedural knowledge e.g., poor assumptions, cause vs. correlation, faulty explanations, generalisations from limited data;
- Justify decisions using scientific arguments, either individual or communal, that contribute to solving contemporary issues or sustainable development.

69. The past decade has seen an explosion in the amount and flow of information and the ability of individuals to access this information. Unfortunately, as well as a flow of valid and reliable information there has been an increasing flow of misinformation, and worse, disinformation. When it comes to scientific information, both valid and mis-informed, all citizens need the competency to judge the credibility and value of the information that commonly surround any science-related issue. The prominence of information and misinformation surrounding the pandemic of 2020 is an excellent example e.g. whether to wear masks, the dangers associated with Covid-19, and the value of possible cures/vaccines.

70. Most individuals' interaction with science will be through secondary sources or secondary data. To evaluate such reports, individuals need to understand how to evaluate the status of sources and expertise, the status of the publication in which the information is published, the role of peer review, standard issues in questioning the quality of the data e.g. accuracy, precision and sample size, and common flaws in arguments (generalising from limited data, distinguishing cause from correlation).

71. A scientifically educated person should understand the importance of developing a sceptical disposition particularly to media reports of single findings in science, recognising 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, to varying degrees, on their content knowledge of science.

72. Therefore, a goal of science education should be to develop the competency required for researching, evaluating and using scientific information for decision making and action for personal, local and global science-related issues. This requires the basic competencies used by fact checkers of "click restraint" and "lateral reading" used to check the credibility of sources (Breakstone et al., 2021). 15-year-olds need to know how to use Wikipedia to establish whether there is any scientific consensus. In addition,

the scientifically educated 15-year-old should be able to identify some of the assumptions, claims, evidence and reasoning in a scientific argument, and be able to construct arguments from the scientific evidence and information they obtain e.g. for vaccination, carbon offsetting, water conservation, air quality. They should also be able to identify common flaws. These include false assumptions e.g. human behaviour does not contribute to climate change; distinguishing correlation from causation e.g. stork population and birth rate in any country, sales of ice cream and shark deaths; faulty explanations e.g. vaccines causing autism, the failure to distinguish between weather and climate - for example "scientists can't predict the weather in two weeks time, how can they predict the climate in 20 years?"; and generalisations from limited data e.g. small samples. In addition, there needs to be a recognition that science is only one factor amongst others such as economic, behavioural and values that inform decisions, and how scientific knowledge and practice interacts with these.

Scientific Knowledge

73. The three competencies developed by an education in science require three forms of knowledge that are discussed below.

Content Knowledge

74. Only a sample of the content domain of science can be assessed in the PISA 2025 science assessment. Hence, it is important that clear criteria are used to guide the selection of knowledge that is assessed. These are that knowledge to be assessed will be selected from the major fields of physics, chemistry, biology, Earth and space sciences such that the knowledge:

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

75. Therefore, it will be assumed that students have some knowledge and understanding of the major explanatory ideas and theories of science e.g. those to be found in Harlen (2010). These include ideas such as our 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 and there has been no attempt to list comprehensively all the ideas and theories that might be seen to be fundamental for a scientifically educated individual. Moreover, it is recognised that within any of these domains, for both content and the practices of science, there exists a hierarchy of progression which should be attended to when formulating items for assessment (Alonzo and Gotwals, 2012).

76. Box 6 shows the content knowledge categories and examples selected by applying these criteria. No claim is made that this is a comprehensive list but 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 the content knowledge. The intention is to convey the idea that citizens must understand concepts from the physical and life sciences, earth and space sciences, and their application in contexts where the elements of knowledge are interdependent or interdisciplinary. Phenomena viewed as subsystems at one scale may themselves be viewed as whole systems at a smaller scale. For example, the transport 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. Hence, applying scientific knowledge and deploying scientific competencies requires consideration of which system and which boundaries apply to any particular context.

77. In addition, understanding many of the contemporary challenges facing humanity and the influence of humans on the planet requires a knowledge of the interdependence of living organisms. That is the scientific knowledge to explain the importance of top predators, the significance of bees, or the impact of deforestation.

Box 6. Knowledge of the content of science in PISA 2025

Physical Systems that require knowledge of:

Structure and properties of matter (e.g. particle model, bonds, 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 and interactions);

Energy and its transfer (e.g. conservation, dissipation, chemical reactions);

Interactions between energy and matter (e.g. light and radio waves, sound and seismic waves, absorption of radiation by carbon dioxide).

Living Systems that require knowledge of:

The concept of organism (including animals, plants and microorganisms, (e.g. viruses, bacteria);

Genes (e.g. expression, heredity/inheritance, biotechnology) and their interaction with the environment;

Cells (including structure and function, energy, respiration (carbon oxidising), photosynthesis (carbon fixing), growth, etc);

Plant and animal systems, their health and maintenance (e.g. circulatory/transport, reproduction, respiration, transport, excretion, digestion/nutrition) and associated inter-relationships;

Biological evolution (biodiversity, genetic variation, adaptation and natural selection);

Ecosystems (e.g. matter and energy flow, food chains, habitat, disruption, e.g. pollution);

The Biosphere (e.g. sustainability in the global ecosystem);

Interactions of humans and their impact and effect on the environment, other species and sustainability.

Earth and Space Systems that require knowledge of:

Structures of the Earth systems (e.g. atmosphere, hydrosphere, geosphere e.g. plate tectonics, seismology);

The finite nature of mineral resources, their use and the effects on the environment in their exploitation.

Energy in the Earth systems (e.g. sources, global warming, plate tectonics, geological cycles, water cycle);

Water, supply and conservation (e.g. fresh water, aquifers);

(continues over page)

Interactions and Change among Earth systems (e.g. climate change, geochemical cycles, constructive and destructive tectonic forces, ocean acidification);

Earth's history (e.g. fossils, origin & evolution, erosion and deposition);

Earth in space (e.g. moon phases, solar systems, galaxies);

The origin of the Universe and the Solar System (e.g. stellar evolution, formation of the planets, Big Bang theory).

78. As well as content knowledge, the scientifically educated individual would understand that the construction of knowledge is dependent on a set of interdependent key practices (National Research Council, 2012) which require scientists to:

- Ask questions about the material world
- Develop and using models
- Plan and carry out investigations
- Analyse and interpret data
- Use mathematics and computational thinking
- Construct explanations
- Engage in argument from evidence
- Obtain, evaluate, and communicate information

79. These practices require either or both procedural and epistemic knowledge which are elaborated next.

Procedural Knowledge

80. 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 is reliant 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 for 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 underpin the collection, analysis and interpretation of scientific data. Such ideas form a body of procedural knowledge which has also been called 'concepts of evidence' (Gott, Duggan, & Roberts, 2008; Millar, Lubben, Gott, & Duggan, 1995).

81. One can think of procedural knowledge as being a knowledge of the standard procedures and practices scientists use to obtain reliable and valid data. Such knowledge is required both to undertake scientific enquiry and engage in critical review of the evidence that might be used to support claims made from the data. It is expected, for instance, that students will know that scientific knowledge has differing degrees of certainty associated with it and can explain why, for instance, that 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 Box 7 convey the general features of procedural knowledge that may be tested.

Box 7. PISA 2025 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 precision (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 their appropriate use;

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;

Given a scientific question, what might be an appropriate design for its investigation e.g. experimental, field based or pattern seeking; the role of controls to establish causality

What processes of peer vetting are used by the scientific community to ensure knowledge claims are trustworthy.

Epistemic Knowledge

82. Epistemic knowledge is a knowledge of the constructs and defining features essential to the process of knowledge construction in science and their role in justifying the knowledge produced by science. As such, epistemic knowledge provides a rationale for the procedures and practices in which scientists engage, a knowledge of the structures and defining features which guide scientific enquiry, and the foundation for the basis of belief in the claims that science makes about the natural world. In short, an explanation and justification of how claims to know in science are justified. The distinction between procedural and epistemic knowledge is exemplified by being able to explain what the control of variables strategy is, which is procedural knowledge, and being able to explain why the use of the control of variables strategy or replication of measurements is central to establishing knowledge in science, which is epistemic knowledge.

83. 15-year-olds should, for instance, know that any particle model of matter is a simplified representation of matter and be able to explain how the Bohr model is a limited model of what we know about the atom and its constituent parts but was based on the best evidence at the time. They would know that the construction of models, be they directly representational, abstract or mathematical, is a key feature of science and that such models are akin to maps rather than accurate pictures of the material world. Essentially the aim of a model is to produce a representation that affords an understanding of a phenomenon, rather than replicate the phenomenon itself (Elgin, 2017). Good models also enable the production of hypotheses and predictions.

84. Scientifically educated 15-year-olds will also understand that scientists draw on data to advance claims to knowledge and that argument is a commonplace feature of the sciences. They should also be aware that there are different types of arguments in

the sciences. For instance, 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) based on the best available evidence.

85. The scientifically educated 15-year-old would have a basic understanding of the collaborative and communal nature of scientific enquiry and how it develops trustworthy knowledge. They would be able to explain how the control of variables strategy enables the production of reliable knowledge. In short, that an observed effect can be attributed to the independent variable. They would know the role and significance of peer review as the mechanism that the scientific community has established for testing claims to new knowledge and for achieving consensus; they would know that error and mistakes are an inherent feature of science; that all new scientific findings are vetted by other scientists who are expert in that domain; that only those that have been peer reviewed are worthy of trust; and that there is a hierarchy of journals within the community e.g. *Science, Nature, Cell, the Lancet*, *New England Medical Journal* etc. They would, for instance, be able to explain the purpose of peer review and replication in minimising error and producing trustworthy knowledge. They could explain that the conception 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'.

86. Box 8 represents what are considered to be the major features of epistemic knowledge. At its core, epistemic knowledge has four elements: A knowledge of the role of models in science, the role of data and evidence in science, the nature of scientific reasoning, and the collaborative and communal nature of scientific enquiry

Box 8. PISA 2025 epistemic knowledge

Epistemic Knowledge

The constructs and defining features of science. That is an understanding of:

The nature of scientific observations, facts, hypotheses, models and theories;

The purpose and goals of science (to produce reliable explanations of the natural world and to predict future events) as distinguished from technology (to produce an optimal solution to human need);

The values of science e.g. a commitment to peer-reviewed publication, objectivity and the elimination of bias.

More specifically, this requires an understanding of:

Models

How understanding of the material world is constructed using physical, conceptual, system and mathematical models in science; e.g., particle model of matter.

The distinction between a model and reality e.g. that a model is a representation of something which may be too small to see or too large to imagine; e.g., Bohr model of the atom.

How models enable predictions and explanations; e.g., Sun-Earth model of daily movements. *(continues over page)*

How the limitations of models (e.g. number of variables, simple v complex models, quality of data provided) constrain their use.

Data and Evidence in Scientific Claims

How scientific claims are supported by data, methods, reasoning and evaluation in science;

How scientific evidence is generated e.g. the nature of the practices undertaken by scientists;

How measurement error affects the degree of confidence in scientific knowledge.

The Nature of Scientific Reasoning

Some of the different forms of empirical enquiry e.g. experiment, field work and its role, controlled experiments, pattern seeking;

The types of reasoning (deduction, abduction, induction, probabilistic thinking) used in establishing knowledge and their goal (to test explanatory hypotheses, or identify patterns and entities) and examples of each e.g. Newton's Laws of Motion*(deduction), Mendelian Genetics (induction), Theory of Evolution (abduction)

The ethical dilemmas raised in scientific practice e.g. animal experimentation, conflicts of interest;

The role of scientific knowledge, along with other forms of knowledge, in identifying and addressing societal and technological issues and its limits.

The Collaborative and Communal Nature of the Sciences

How specific scientific research is funded and supported e.g. government, private and the mechanisms for deciding;

The importance of consensus in warranting belief;

How peer review helps to establish confidence in scientific claims and is dependent on a scientific community;

Key scientific practices undertaken by scientists to produce shared knowledge, their role and their collaborative nature;

The limits to certainty and confidence in scientific findings, how it is expressed, the evolution of certainty and the role of consensus;

How scientific findings are communicated within the community and to the public (e.g. pre-prints, peer reviewed journals, public communication.

87. Epistemic knowledge is most likely to be tested in a pragmatic fashion in a context where a student is required to interpret and answer a question that requires some epistemic knowledge rather than assessing directly whether they understand the features in Box . For instance, 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.

Science Identity

88. The inclusion of the identity construct as a major dimension for the PISA 2025 construct of science competency and outcomes is based on the principle that while scientific knowledge and competencies are important and valuable for young people's futures, identity outcomes are also crucial for supporting agency and active citizenship in a rapidly changing world. Such outcomes are the extent to which young people feel meaningfully connected to science, recognise themselves and feel recognised by others as science interested/competent (Carlone & Johnson, 2007), and engage with the sciences as critical consumers and decision-makers in their daily lives (Bell et al., 2018).

89. Young people's views of themselves as individuals who are both interested in, and value science and scientific ways of thinking is captured by the construct of science identity. The aim of PISA is to assess the knowledge and competencies to engage scientifically with the world by 15-year-olds, which would be incomplete without a measure of young peoples' sense of agency, attitudes, and values in relation to science. In short, if the knowledge and competencies of the sciences are not valued as a way of thinking and being in the world, science education has failed to achieve one of its major goals. Given the inclusion of the new competency "Research, evaluate and use scientific information for decision making and action" which places even more emphasis on the capability of 15-year-olds to use such knowledge, consideration of these traits of a scientific identity becomes ever more important. It is not enough to 'know' science if there is no meaningful connection that then translates into its common use.

90. The identity construct goes beyond considerations of short-term attitudes and affective responses to science and science classrooms events, to frame engagement with science and longer-term aspirations in terms of self-processes that are bounded by sociocultural structures and interactions with others that shape a sense of self (Ashbacher et al., 2014). The construct has proved powerful in interpreting the experience of science and science classrooms of minority and culturally and ethnically diverse students (including indigenous students, immigrant communities) (Calabrese Barton et al., 2013). As such it provides a strong critical and social justice perspective on the interactions of students with science in schools and provides an important perspective for PISA in reporting on science competencies at national and global levels (Archer et al., 2017; Archer, DeWitt & Osborne, 2015). For all students, their identification with science has been shown to mediate learning.

91. The identity construct is complex, however. From a measurement perspective it encompasses a range of constructs related to perceptions, dispositions and values, and attitudes/affect. These include student self-concept (Jansen et al., 2015), which is a measure of their perception of competency in science; self-efficacy (Bandura, 1997), which is a measure of their perception of their ability to perform science-related tasks in everyday life; student agency; motivation; epistemological beliefs; and science capital (Archer, Dawson, DeWitt, Seakins & Wong, 2015). Self-efficacy and collective efficacy are key skills that help determine whether youth believe they can work on current issues and how well they are able to do so.

92. Science capital is a sociological construct referring to science-related forms of cultural and social capital (Bourdieu, 1992, 2010). From a measurement perspective it is seen as a mix of four main components: (i) science-related knowledge and understanding; (ii) science-related attitudes and dispositions (e.g. feeling a connection with science; seeing school science as relevant to my daily life); (iii) engaging with science for leisure/pleasure (e.g. consuming science-related social media); and (iv) science-related social capital (e.g. knowing science-interested people; being supported by significant others to develop

and pursue science interests) (Archer et al., 2015). Together, these elements of science capital support a young person's identification with science – that is, how far they can see themselves in their social context as being 'a science person' and the extent to which they can critically appraise and use science within their wider lives. Attitudes, which were a primary dimension for PISA 2015, are subsumed under this frame of identity.

93. A major distinction within the attitudes literature (Gardner, 1975; Osborne, Simon, & Collins, 2003; Tytler, 2014) is that between attitudes towards science, and scientific attitudes. While the former is measured by the level of interest displayed in scientific issues and activities, the latter is a measure of a disposition to value ways of thinking and working scientifically, including respect for evidence as the basis for claim making, explanation, and decisions.

94. Such a binary distinction, however, is inadequate. For instance, recently there has been interest in aesthetic dimensions of scientists' work (Wickman, 2006) and of student responses to aspects of school science (Anderhag. Hamza & Wickman, 2015; Jakobson & Wickman, 2008; Wickman, Prain & Tytler, 2021), which associate feelings such as appreciation, interest, wonder, or even awe with scientific phenomena, specific living entities such as insects, the workings of a TV, the explanation for the patterns in moon phases, ways of transforming data, or the evidence-based nature of a scientific argument. The construct of a scientific aesthetic emphasises that there exists a continuity between meaning and feeling (Dewey, 1929/1996; Lemke, 1990; 2015) and all conceptual work involves some aesthetic commitment. Richard Dawkins (1997), for example, describes the "spine-shivering, breath-catching awe ... that modern science can provide." Charles Darwin famously underscored the grandeur in the view of life suggested by his theory of natural selection (Darwin, 1968).

95. In addition, individuals who are prone to experiencing awe on a regular basis are known to have an increased tolerance for ambiguity and uncertainty (Shiota, Keltner, & John, 2006). Gottlieb et al. (2018) have shown that the disposition to experience awe predicts a more accurate understanding of how science works, rejection of creationism, and rejection of unwarranted teleological explanations more broadly. Developing a scientific identity can, therefore, be viewed as the development of a 'taste' for science (Anderhag, 2017, drawing on Bourdieu, 1984). This is consistent with views from the psychological literature showing the reciprocal relationship between cognition and affect (Hidi, Renninger & Krapp, 2004; Schiepe-Tiska, 2016).

96. Environmental crises are a pressing global concern. Threats to the environment are increasingly apparent in students' everyday lives including an increasing focus in the media. Students are challenged to understand and respond to complex environmental issues which involve scientific knowledge and may require personal decision making and action. Knowledge of and concern for environment challenges allied with a disposition of hope are important ingredients of agency in the Anthropocene (Li & Monroe, 2017; 2019; Ojala, 2015), and part of the PISA 2025 identity construct.

97. The science identity construct in PISA 2025 draws on a range of the elements contributing to a scientific identity, reflecting the need to assess competencies relevant to life in the 21st century and emphasising particularly student ability to use scientific information to inform decision-making and agency – elements which will be measured both in the cognitive and non-cognitive instruments.

Defining Science Identity for PISA 2025

98. The PISA 2025 assessment will evaluate the following elements of science identity:

Science Capital & Epistemic Beliefs

1. Science capital (science-related knowledge, engagement with science, and social capital)
2. Epistemic beliefs– general values of science and scientific enquiry

Science Capital: Attitudes and Dispositions

3. Science self concept (sense of self in relation to science including future participation)
4. Science self efficacy
5. Enjoyment of Science
6. Instrumental motivation

Environmental Awareness, Concern and Agency

7. Environmental awareness
8. Environmental concern
9. Environmental agency

99. These areas were selected for measurement because they are important attributes of a scientifically educated individual.

100. Science capital is synthetic measure of the degree of knowledge of science that an individual has, their engagement in activities of a scientific nature both formally and informally, their attitudes and dispositons and their knowledge and understanding of scientific work gained from outside of school e.g. if their parents work in science or have scientific pursuits.

101. Epistemic beliefs shown in Box 9 are closely related to students' valuing of scientific perspectives and approaches to enquiry involving an appreciation of the objects, products and processes that drive scientific exploration. Evidence of this dimension of identity could include a commitment to evidence as the basis of belief for explanations of the material world; being comfortable with uncertainty and the notion of risk; valuing evidence-based argument and debate as a means of establishing the validity of any idea; and a commitment to the scientific approach to enquiry when appropriate.

102. As part of epistemic beliefs, a critical disposition is required for the competency 'research, evaluate and use scientific information for decision making and action'. Elements of critical disposition in science that would be highly desirable for young people to develop would be: the capacity and confidence to be critical consumers of science; the disposition to use science as a part of their intellectual toolkit in making decisions that involve multiple forms of knowledge; a recognition of competing values and knowledge claims about science-related issues; a concern with issues of equity associated with science and technology development and its deployment, and presenting a considered reasoned stance on science-related issues that values scientific evidence.

103. Of relevance here is a critical orientation towards the role of science in identifying and dealing with environmental/sustainability issues, including designing scientific solutions that contribute to equity and social justice. This is reflected in a concern for the environment and actions that will sustain the planet and a willingness to undertake appropriate scientifically informed actions. In particular, this disposition is demonstrated by the ability to recognise the complexity of many environmental issues and identify

the competing scientific principles and social considerations in deciding on or advocating appropriate practices.

104. Attitudes and dispostition towards science shown in Box 10 play a significant role in students' interest, attention, and response to science and technology, and to issues that affect them in particular. One goal of science education is to develop attitudes that lead students to engage with scientific and science-related issues. Such attitudes are needed to address the personal, local, national, and global issues that young people will encounter in their lives. Interest in science also has an established relationship with achievement, and aspirations to further study, careers, and lifelong learning in science. For instance, there is a considerable body of literature which shows that for most individuals who pursue scientific careers, interest in science was established by age 14 (Ormerod & Duckworth, 1975; Tai, Qi Liu, Maltese, & Fan, 2006). Policy concerns in many OECD countries about the number of students, particularly females, choosing to pursue the study of physics, engineering and computer science make the measurement of attitudes towards science an important aspect of the PISA assessment.

105. For PISA 2025 the earlier constructs of environmental awareness and environmental optimism have been modified and extended to environmental awareness, environmental concern, and environmental agency shown in Box 11. Given the major challenges represented by threats of anthropogenic climate change, biodiversity loss, and more recently the global pandemic, and the significant movements based on youth concern for intergenerational justice seen, for instance, in the youth strikes for climate, there is a pressing need to explore identity dimensions related to environmentally related competencies, concerns, and agency. To what extent do young people acknowledge that science is core to providing solution to these crises and to what extent do they see themselves as having any agency to engage with and act on these issues at the personal, local, and global levels as appropriate?

Box 9. Science Capital and Epistemic Beliefs

Science Capital

This dimension of scientific identity is indicated by:

An understanding of the nature of some scientific work

The general level of knowledge of scientific ideas

A feeling of connection to science and the personal relevance of science

Engagement with science-related activities at home and in school

Knowledge of and support by science-interested people

Epistemic Beliefs

This dimension of scientific identity is indicated by:

A commitment to evidence as the basis of belief for explanations of the material world.

A commitment to scientific approaches to enquiry when appropriate.

A valuing of critique as a means of establishing the validity of any idea.

Developing an interest in scientific phenomena and associated models and explanations.

Trust in claims made by a consensus of scientists and domain specific experts compared to other sources of information

A recognition that uncertainty is an inherent feature of any scientific inquiry and its implications.

A recognition that scientific knowledge evolves and changes

Understanding that science can make an important contribution to solving social and environmental problems.

Box 10. Attitudes and Dispositions

Attitudes and Dispositions

This is a dimension of science identity indicated by:

A willingness to engage with science related issues and consider the issues critically using both science and other forms of knowledge or values.

How closely the individual identifies with science: recognition by self and others of competency to engage with science related phenomena.

How able the student perceives they are at the sciences.

The level of interest students have in pursuing scientific careers or the study of a science after school.

The range of extra-curricular and out-of-school science activities that students engage in.

How much students like learning about the sciences both in and out of school.

Box 11. Environmental awareness, concern and agency

Environmental awareness, concern and agency

This construct is indicated by:

Taking a critical, evidence-informed perspective on personal and socially relevant environmental issues (including environmental awareness, concern, and agency).

Awareness of environmental issues and recognition of the scientific and social complexity underlying environmentally sustainable actions.

A concern for the environment and sustainable living and the issues of equity and social justice they raise.

Critical evaluation of the role of science and other factors in sustainability practices.

A disposition to take and promote environmentally sustainable practices.

A sense of personal agency which is informed by scientific and environmental understanding.

106. Further detail of some of these constructs can be found in the PISA 2025 Questionnaire Framework and in the book Science-Related Outcomes: Attitudes, Motivation, Value Beliefs, Strategies (Schiepe-Tiska et al., 2016) written by the team that developed the science framework for PISA 2015.

5. Assessment Features

Cognitive Demand

107. A key feature of the PISA 2025 framework is the definition of levels of cognitive demand within the assessment of science 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 the test taker population that is successful in solving the item correctly and thus assesses the overall facility of the test taker population with an item, whereas cognitive demand refers to the type of mental processing required (Davis & Buckendahl, 2011). Care needs to be taken to ensure that the depth of knowledge required, i.e. the cognitive demand required of students, 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 consider many items of knowledge – each of which are easily recalled. Thus, not only should the PISA test instrument discriminate in terms of performance between easier and harder test items, but 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 & Nitko, 2011).

108. 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 which 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) - and the frameworks described briefly below have served to develop the knowledge and competencies in the PISA 2025 Framework. These have been largely based on categorisations of knowledge types and associated cognitive processes that are used to describe educational objectives or assessment tasks.

109. Bloom’s Revised Taxonomy (Anderson & 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.

110. 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 performance 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 performances. 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 & Collis, 1982) which describes a continuum of student understanding through five distinct

stages of pre-structural, unistructural, multistructural, relational, and extended abstract understanding.

111. More recently Tekkumru-Kisa, Stein and Doyle (2020) have published a schema that discusses the levels of demands of tasks and distinguishes the level of thinking needed to engage in different types of tasks and scientific practices. This provides some insights into the nature of higher order tasks and the demands they make which are particularly salient for this framework and items that might assess the competencies at higher levels.

112. 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:

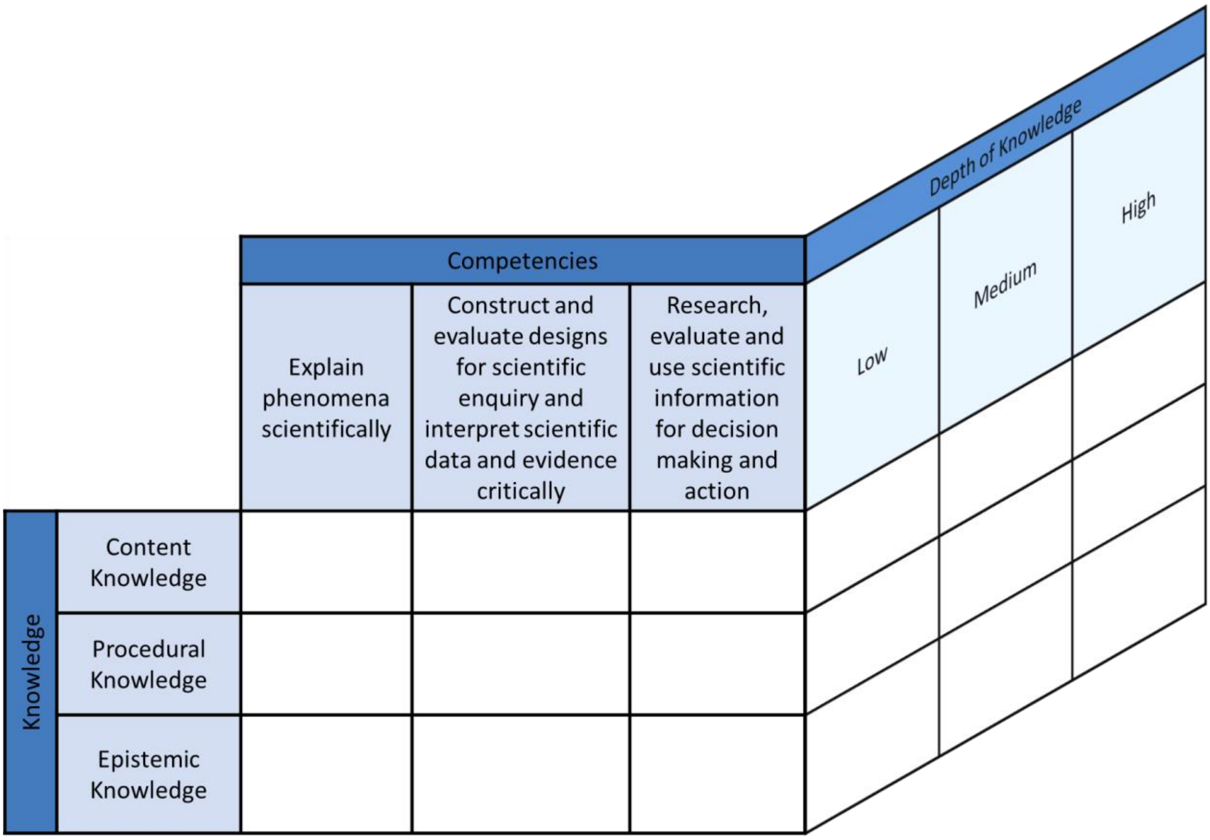
a. Too much effort is made to fit test items into particular cognitive frameworks which can lead to poorly developed items;

b. Misclassification between intended and actual demand with frameworks defining rigorous, cognitively demanding goals, and 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.

113. The approach taken for the PISA 2025 Framework is to draw on these frameworks in developing our definition of cognitive demand. As the competencies are the central feature of the framework, the cognitive framework needs to assess and report on them across the student ability range. Webb's Depth of Knowledge Levels offer a taxonomy for cognitive demand that requires items to identify both the cognitive demand from the verbal cues that are used, e.g. analyse, arrange, compare, and the expectations of the depth of knowledge required.

Figure 2. PISA 2025 framework for cognitive demand



114. The grid above in Figure 2 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 (L)

Carrying out a one-step procedure, for example one that requires the recall and use of a fact, term, principle or concept or locating a single point of information from a graph or table. A one step procedure might also involve sorting using a single criterion, classifying with easily observable, macroscopic features, identifying one element of evidence that does or does not support a claim, or using everyday or simple school science concepts for explanations in familiar contexts e.g. why a metal spoon gets hot when placed in a hot drink.

Medium (M)

Use an application of any of the three forms of (content, procedural, epistemic) 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 to support or question a claim, construct an argument from limited evidence in familiar contexts, or use standard models to explain in familiar contexts. Cognitively, this would require either the use of two or more steps in the reasoning using one idea, or relating two ideas/pieces of information in one step generally in familiar contexts. Identify from two or more pieces of evidence their appropriate or inappropriate use.

High (H)

Analyse more complex information or data, synthesise or evaluate evidence, justify, reason given various sources, develop a plan or sequence of steps to investigate and respond to a problem, or critique a flawed argument using complex or abstract concepts. Cognitively, this would require either the use of two or more steps in the reasoning, the use of two or more ideas, the evaluation of divergent claims, the consideration of rebuttals or qualifiers often in unfamiliar contexts, and the ability to make connections among two or more representations to develop meaning.

115. Thus, 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 made 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 or depth of knowledge it requires and the cognitive operations that are required to process the item.

116. 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.

117. This four-factor approach allows for a broader measure of scientific competence 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, its relative simplicity offers a framework for minimising the problems encountered in applying such frameworks. The use of this cognitive framework will also facilitate the development of an a priori definition of the descriptive parameters of the reporting proficiency scales (see Figure).

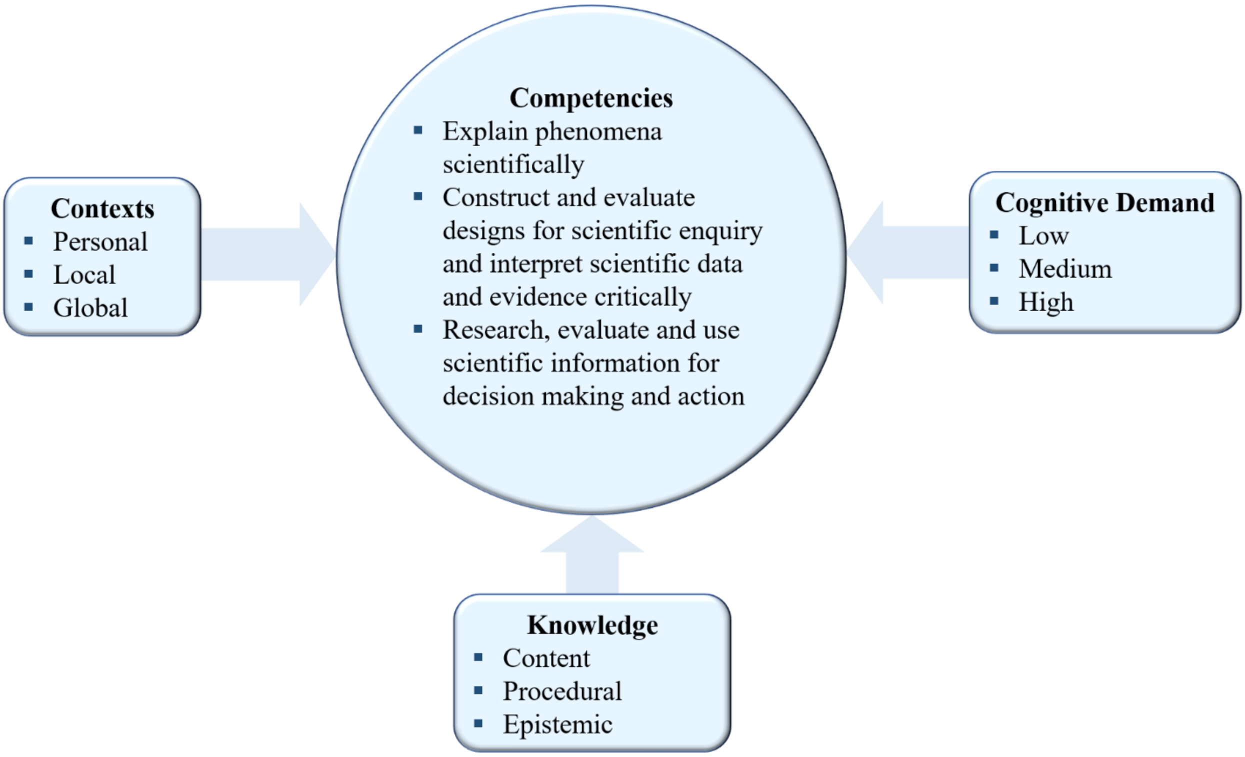
Test characteristics

118. In accordance with the PISA definition of science outcomes, test questions (items) will require the use and application of the scientific competencies and knowledge within a context.

119. Figure 3 is a variation of Figure 1 that presents the basic components of the PISA framework for the 2025 scientific competency 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 both synthetically as a tool to plan assessment exercises, and analytically as a tool to study the results of standard assessment exercises. As a starting point to construct assessment units, 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.

120. 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 included non-static stimulus material, such as animations and interactive simulations for the first time. These will also be included in the test for PISA 2025 using any enhanced facilities available. The items are a set of independently scored questions of various types, as illustrated by the examples already discussed.

Figure 3. A tool for constructing and analysing assessment units and items for the Cognitive Questionnaire



121. The reason PISA employs this unit structure is to facilitate the employment of contexts that are as realistic as possible, reflecting the complexity of real situations, while making efficient use of testing time. Using situations about which several questions can be posed, rather than asking separate questions about a larger number of different situations, reduces the overall time required for a student to become familiar with the material in each question. However, the need to make each score point independent of others within a unit needs to be considered. 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.

122. PISA 2025 test units will require the use of all three scientific competencies and draw on all three forms of science knowledge. In most cases, each test unit will assess multiple competencies and knowledge categories. Individual items, however, may only assess only one form of knowledge and one competency.

123. The need for students to read texts to understand and answer written questions on science raises an issue of the level of reading comprehension that will be required. Stimulus material and questions will 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 will be limited. Questions within the domain of science that assess reading or mathematical literacy will be avoided.

Item Response Formats

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

Simple multiple-choice: Items calling for

- selection of a single response from four options
- selection of a "hot spot," an answer that is a selectable element within a graphic or text.

Complex multiple-choice: Items calling for

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

Constructed response: Items calling for written or drawn responses.

- Constructed response items in Science typically call for written responses 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. of a graph or diagram). For computer delivery, any such items will be supported by simple drawing editors that are specific to the response required.

125. Also, in PISA 2025, as in PISA 2015, some responses will be captured by interactive tasks using simulations, for example, a student's choices for manipulating variables in a simulated scientific enquiry or require the construction of an explanation for the observed behaviour of the simulated system. Responses to these interactive tasks will likely be scored as complex multiple-choice items. Some kinds of responses to interactive tasks may be sufficiently open-ended that they will be treated as constructed response.

Assessment structure

126. For PISA 2025, computer-based assessment will be the primary mode of delivery for all domains. All new science items will be developed for the computer-based assessment and where possible for paper-based assessment. A paper-based assessment instrument will be provided for countries choosing not to test their students by computer.

127. The desired balance between the three knowledge components, content, procedural and epistemic knowledge is shown in Table 3 in terms of percentages of score points. Table 3 also shows the target distribution of score points among the various knowledge categories. These weightings are broadly consistent with the previous framework and reflect a consensus view amongst the experts consulted in the writing of this framework.

128. Those elements of the cognitive science framework that contribute to agency in the Anthropocene will be measured using the scale provided below in the Environmental section to provide a measure of the extent to which students have this competency.

Table 3. Target distribution of score points for knowledge

	Systems			
Knowledge types	**Physical**	**Living**	**Earth & Space**	**Total over systems**
Content	15-20%	15-20%	10-15%	38-48%
Procedural	10-13%	10-13%	7-10%	27-33%
Epistemic	8-11%	8-11%	7-10%	24-30%
Total over knowledge types	**37%**	**37%**	**26%**	**100%**

129. The target balance for scientific competencies is given in Table . These weightings have been chosen so that the assessment is evenly split between items that draw predominantly on content knowledge and items that draw predominantly on procedural and/or epistemic knowledge.

130. Item contexts will be spread across personal, local/national and global settings roughly in the ratio 1:2:1 as was the case in PISA 2015. A wide selection of areas of application will be used for units, subject to satisfying as far as possible the various constraints imposed by the distribution of score points shown in Table 3 & 4.

Table 4. Target distribution of score points for scientific competencies

Scientific Competencies	**% of score points (approx.)**
Explaining phenomena scientifically	36-44%
Construct and Evaluate designs for scientific enquiry and interpret data and evidence critically	24-36%
Research, evaluate and use scientific information for decision making and action	24-36 %
TOTAL	**100%**

Reporting scales

131. To meet the aims of PISA, the development of scales of student achievement is essential. 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 PISA 2006 framework therefore defined explicitly the parameters of increasing competence and progression, allowing item developers to design items representing this growth in ability (Kane, 2006; Mislevy and Haertel, 2006). Initial draft descriptions of the scales are offered below, though it is recognised that these may need to be modified as data are accumulated after field testing of the items. Although comparability with the PISA 2015 scale descriptors (OECD, 2016) has been maximised in order to enable trend analyses, the new elements of the PISA 2025 framework such as the new competency "Research, evaluate and use scientific information for decision making" have also been incorporated. The scales have also been extended by the addition of a level '1c' to specifically address and provide a description of students at the lowest level of ability who demonstrate very minimal evidence of scientific competency and would previously not have been included in the reporting scales. This has drawn on the work undertaken in 2016-18 to develop a set of PISA tests for developing countries known as PISA-D. The initial draft scales for PISA 2025 therefore propose more detailed

and more specific descriptors of the levels of Scientific Competence, and not an entirely different model.

Trend Reporting

132. To report trends over the years, a number of items are repeated in each cycle. These enable student overall performance on the test to be compared with previous years. Only the trend in overall performance can be reported and not the trends in individual competencies – especially as these change each 9 year cycle.

Table 5. Initial Draft Reporting Scale proposed for PISA 2025

Level	Descriptor
6	At level 6, working in unfamiliar contexts, students can draw on a range of scientific ideas of high demand from different disciplines to build models, consider their limitations, and use those models to construct or evaluate scientific explanations of complex phenomena. They can apply those explanations to make predictions not only about the phenomena but also about potential future developments or implications for society. Students can identify and explain the purposes of particular enquiries of different types, and which question they are answering. They can apply epistemic and procedural knowledge to evaluate competing designs of complex enquiries such as experiments, field studies or simulations and justify their choices of design. They can transform data from one representation to another and correctly interpret more complex data sets. Students can evaluate the interpretation of data sets drawing on procedural and epistemic knowledge to make reasoned judgements about their accuracy and precision. Drawing on multiple sources of information of high cognitive demand, containing both textual and graphical information, students can identify those sources which are most trustworthy based on one or more scientific criteria or more sophisticated fact-checking procedures. They can provide a justification for their choice drawing on content, procedural or epistemic knowledge of science, and/or social, ethical or economic considerations. In addition, they are able to identify flaws in sources of scientific information – either in their trustworthiness, their use of data, or in the arguments from the evidence. Based on their evaluation, they can provide justifications considering multiple issues for possible decisions and actions.
5	At level 5, students can draw on a range of scientific ideas of medium to high demand to identify and construct explanations of familiar phenomena in all contexts. They can use these explanations to make predictions. They are able to identify both the strength and the limitation of models. Drawing on procedural and epistemic knowledge, students can distinguish scientific and non-scientific questions, and identify and explain the purposes of enquiries of different types. They are able to apply epistemic and procedural knowledge to evaluate alternative experimental/investigative designs and justify their choices. They can interpret more complex data representations and evaluate with reasons whether a given interpretation is flawed and explain what a more appropriate interpretation would be. Drawing on multiple sources of information of medium to high cognitive demand containing both textual and graphical information, students are able to identify those sources which are most trustworthy based on one or more scientific criteria or standard fact-checking procedures. They are able to provide a justification for their choice drawing on either content, procedural or epistemic scientific knowledge and either a social, ethical or economic consideration. In addition, they should be able to identify a flaw in a source - either in its trustworthiness, its use of data, or in the arguments it uses. Based on their evaluation, they can provide a reasoned justification for possible decisions and actions.
4	At level 4, students can construct and evaluate scientific explanations of phenomena by drawing on a range of scientific principles and various representations of medium to high cognitive demand. Given a model, they are able to identify either a strength or a limitation. Drawing on procedural and epistemic knowledge they can propose experimental or investigative designs involving two or more independent variables in a limited context. They are able to justify a design for an enquiry using procedural or epistemic knowledge. They can interpret straightforward data representations and evaluate the validity of scientific claims based on such data. Given a need for information to inform decision making or action, students can draw on multiple sources of medium cognitive demand, containing both textual and graphical information, to identify which is most trustworthy using a basic fact-checking procedure or another science-based criterion. They are able to provide a justification for their choice. In addition, given several possible errors in a source or its interpretation, they are able to select an appropriate weakness and explain the flaw.
3	At level 3, students can construct or evaluate scientific explanations and models of phenomena with relevant cueing or support, by drawing on scientific principles and representations of medium cognitive demand. Given a simple model, they are able to identify either a strength or a limitation of the model. They can provide a justification for a simple experimental design involving control of variables or sampling of a population using elements of procedural and epistemic knowledge. Given an interpretation of a set of data, they are able to identify a flaw in the interpretation using procedural or epistemic knowledge. Alternatively, offered a set of simple data presented in a tabular or graphical representation, they are able to provide a valid interpretation. Given a need for information for decision making or action from sources of medium cognitive demand, students can identify which sources are relevant and summarise their arguments. They can use one or more criteria to judge whether a source is trustworthy and provide a justification for their choice.
2	At level 2, students can identify an appropriate scientific explanation from a non-scientific explanation for everyday/common scientific phenomena in familiar personal, local or global contexts, by drawing on appropriate content knowledge of low to medium cognitive demand. They can offer a simple explanation of an everyday or familiar scientific phenomenon such as why you might need a balanced diet that draws on basic school science concepts. They are able to evaluate designs for simple enquiries drawing on elements of procedural knowledge and identify appropriate interpretations of data sets with simple relationships and identify outliers and possible reasons for their occurrence. Using their epistemic knowledge, they can identify appropriate explanations for variations in measurement. Given a need for information for decision-making or action, students can identify relevant sources of information from several of low to medium cognitive demand, that is needed to inform action on a given scientific problem and summarise its main argument. Using a single criterion e.g. relevant expertise, scientific consensus, they can identify whether the source is trustworthy.
1a	At level 1a, in familiar personal, local or global contexts, students can identify a claim or explanation of a simple phenomenon drawing on scientific information or evidence of low cognitive demand. Students can identify one relevant source of information from several, that is needed to inform action on a given scientific problem and identify the main finding or argument. Students can choose the most appropriate experimental design involving control of one variable from several by drawing on a low-level procedural knowledge.
1b	At Level 1b, in everyday personal, or local contexts, students can recognise a claim or explanation of a macroscopic phenomenon communicated in simple scientific language by recalling everyday scientific information or observations. Students can identify more than one relevant source of information needed to inform action on a given scientific issue from several. Drawing on low level procedural knowledge, they can identify from two experimental designs which would be the better to answer a given question. They can select from several interpretations of a simple data set/graphical display with a low level of cognitive demand which is the better.
1c	At level 1c, in everyday personal contexts, students can recognise an explanation of a common macroscopic phenomenon communicated in everyday language by recalling elements of everyday scientific information or observations at the lowest level of cognitive demand. Given a simple question, they can recognise a single source of scientific information that might be relevant. They are able to select which is better of two interpretations of a simple set of data.

133. The proposed level descriptors are based on the 2025 framework described in this document and offer a qualitative description of the differences between levels of performance. The factors used to determine the demand of items assessing science achievement that have been incorporated into this outline of the proficiency scales include:

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

134. The intention of the test is to distribute items equally across all levels.

6. Environmental Science

Introduction

135. Human impact is significantly changing Earth's systems (IPCC, 2021). These changes began with industrialisation in the 1800s and have increased exponentially since 1950 (Lewis & Maslin, 2015). While humans may have the highest living standards and life expectancy ever (Pinker, 2018, Rosling & Rönnlund, 2019), the overwhelming majority of other living organisms are in crisis – a crisis that is threatening humanity, as well. Climate change and biodiversity loss is impacting all species, many irrevocably, and precipitating the sixth mass extinction (Dirzo et al., 2014). Human impact in the Anthropocene has led to significant disruptions to the systems within the biosphere, hydrosphere, geosphere, and atmosphere (IPCC, 2021). Thus, humanity faces an uncertain future. For many people, and young people in particular, climate change is seen as the greatest challenge of our time. To meet this challenge, scientific knowledge and reasoning is an essential element for decision making individually, communally, and globally to mitigate impacts and adapt to more sustainable practices and systems (Steffen et al., 2011).

136. With an increasing population of more than 7 billion people and finite natural resources, the challenges include: ensuring clean air and water, providing food security, managing diseases, generating renewable energy, striving for health and wellbeing, and managing our own living choices responsibly to ensure ample resources for all species and future generations (IPCC, 2021; Barnosky et al., 2012; Rockstrom et al., 2009). Dealing with these challenges, and the many others resulting from human-induced climate change and environmental impact, will require that young people are able to understand and act on contributions from science and technology, alongside other disciplines and knowledge systems (Schipper et al., 2021).

137. Scientifically informed 15-year-olds will have to evaluate the sources of information about these issues, as well as use creative and systems thinking to explore and consider appropriate courses of action to regenerate and sustain Earth's systems (Young et al., 2006). Scientific knowledge is important in informing the decisions and actions that contribute to individuals and communities making informed, sustainable living choices and developing the critical thinking, media literacy, and hopefulness required to address this challenge (Monroe et al., 2019).

138. In addition, an appreciation of diverse knowledge systems and respect for cultural heritage also contributes to potential solutions (Reyes-Garcia et al., 2019: Salomon et al,. 2019). Young people need to be aware of how systems of governance and power might frame and impact issues that are social, environmental and ecological (Berkes & Folke, 1998; Muller, Hemming & Rigney, 2019; Young et al., 2006). Young people will benefit from working across generations to address socio-ecological inequities and to create and sustain healthy communities (Thiery et al, 2021). This will require education to support young people to develop an ethic of care and justice (Merrett, 2004: Skovdal & Evans, 2017) based on a worldview that can be enhanced through a science education that presents and ecocentric worldview, which includes humans as part of the environment rather than separate from it. Such a systems thinking perspective is necessary to look beyond patterns and linear relationships to support the design and enactment of sustainable living choices. For instance, systems thinking is usefully applied when considering the impact of personal choices (such as whether to adopt a predominantly vegetable-based diet or use public transport); local choices (e.g., working toward reducing the availability of single-use plastic); community actions (e.g., collaborating with others to engage in civic actions to

change the regional transportation system); and global choices (e.g., supporting international policy to reduce fossil-fuel dependence).

139. Agency will be required for 15-year-olds to enact the necessary changes to meet their goals (OECD, 2019). Agency involves undertaking critical appraisal of complex systemic issues and evaluating whether evidence-based claims on these issues are made by legitimate experts. It involves using their evaluation to make decisions about setting goals to bring about change and how to take responsible action, as well as making decisions by examining and reasoning with the evidence in a scientific way. The ability to make decisions to act responsibly for themselves, and with others, is a measure of agency in the Anthropocene. For example, demonstrating agency in the Anthropocene involves reflecting on personal lifestyle choices and implementing change, influencing others to reflect and change, and providing feedback to organisations and governments about changes required. These actions contribute to better management of resources (such as in circular economies where wastes are eliminated as materials are (re)cycled).

140. Science education is critical in providing young people with a basic understanding of Earth's systems and their interactions with human systems. Understanding the degree to which these socio-ecological issues are complex and their interactions through the use of appropriate tools (such as systems mapping) is essential to prepare young people to address contemporary challenges, such as mitigating and adapting to climate change. In these uncertain times, young people also need the following set of attitudes and dispositions to work individually, with others, and across generations for systemic change and sustainability:

- **Systems Thinking,** which s the ability to recognise complex interactions among relevant variables and understand the consequences of changes to those variables;
- **Self-efficacy**, which refers to the belief that one can act;
- **Collective efficacy**, which is believing that one's group can meet their goals;
- **Outcome expectancy**, which is the belief that one's actions will make an impact on the issue of interest;
- **Agency**, which is the perception that one influences one's own actions and circumstances; and
- **Hope**, which is the sense that there is a way toward a possible future that is worth achieving.

141. These components are intertwined, as the ability to recognise complex systems requires consideration of how any intervention might improve a situation, the belief that one has the agency and efficacy to take the desired actions, and that achieving any goals contributes to a more hopeful and desirable vision of the future (Ajzen, 1985; Snyder, Rand, & Sigmon, 2001). And, those who believe their group can work effectively tend to have a greater sense of their own self-efficacy (Jugert et al., 2016). Similarly, outcome expectancy is a core element of both hope and efficacy.

142. Systems thinking capablities are important across all areas of science education and environmental issues provide important examples of the need to consider an issue at the systemic level. Systems can be ecological or social, or a combination of both. While many educators teach young people to identify the function of components of a system (such as planets and stars or veins and lymph nodes), the interactions between these components often create new structures and functions. Seeking to understand a system and its complex relationships enables recognition of how and when changes in one variable in a system can affect others and its potential mitigation.

143. Hope in particular has been demonstrated to be an essential attitude for addressing complex socio-ecological issues. Without hope, the belief that the current predicament will not change or improve may result in anxiety, depression, and helplessness (Peterson et al., 1993). The spatial and temporal scale of contemporary environmental issues such as climate change and biodiversity loss have led to a definition of hope that includes actions that can be taken with others (Li & Monroe, 2017; 2019) or collective efficacy. This arises when individuals work with communities to effect change (Ojala, 2012; Li & Monroe, 2017; 2019; Ardoin, Bowers, & Wheaton, 2022). Coupling a sense of hope with knowledge about the complexity of interconnected Earth systems will enable environmental and social challenges to be addressed (Ojala, 2015). Key to this outcome is the belief that possible solutions and pathways exist that can be taken by individuals, communities, organisations, businesses, and governments (Li & Monroe, 2019). Thus measuring whether young people have a sense of hope about the future is important in assessing the degree to which they have agency in the Anthropocene.

Agency in the Anthropocene

144. The central construct of the environmental related outcomes of students' science education to be measured is defined as Agency in the Anthropocene (Box 12). A full elaboration of this construct and its associated competencies can be found in the supporting document (OECD, 2022).

Box 12: Agency in the Anthropocene

Agency in the Anthropocene: A Definition

Agency in the Anthropocene requires understanding that human impacts already have significantly altered Earth's systems, and they continue to do so. Young people with Agency in the Anthropocene believe that their actions will be appreciated, approved, and effective as they work to mitigate climate change, biodiversity loss, water scarcity, and other complex issues and crises. Agency in the Anthropocene refers to ways of being and acting within the world that position people as part of (rather than separate from) ecosystems, acknowledging and respecting all species and the interdependence of life. Those with Agency in the Anthropocene acknowledge the many ways societies may have created injustices and work to empower all people to contribute to community and ecosystem well-being. They demonstrate hope, resilience, and efficacy in the face of crises that are both social and ecological (socio-ecological). Moreover, they respect and evaluate multiple perspectives and diverse knowledge systems and demonstrate their ability to engage with other young people and adults, across the generations, in civic processes that lead to improved community well-being and sustainable futures. Young people with Agency in the Anthropocene work individually and with others across a range of scales, from local to global, to understand and address complex challenges that face all beings in our communities.

Competencies for Agency in the Anthropocene

145. The Anthropocene represents a time of significant challenge to our social structures and Earth systems. Addressing these challenges will require that we consider several

changes: change in the ways that we as humans interact with each other and our environment; change in our environment, overall; change in our technologies; and change in our value systems. A young person growing up into this anthropocentric world requires three essential competencies that underpin the concept of Anthropocene Agency in PISA 2025 – elements of which will be measured by the PISA 2025 Science Assessment defined in Box 13.

Box 13: Competencies for Agency in the Anthropocene

A 15-year-old student who demonstrates Agency in the Anthropocene can:

1. Explain the impact of human interactions with Earth's systems.
2. Make informed decisions to act based on evaluation of diverse sources of evidence and application of creative and systems thinking to regenerate and sustain the environment.
3. Demonstrate hope and respect for diverse perspectives in seeking solutions to socio-ecological crises.

Agency in the Anthropocene Competencies in Action

146. A range of abilities underpin each of these competencies required for Agency in the Anthropocene. Those abilities are described in more detail below. The competencies are a mix of both cognitive and non-cognitive elements, reflecting the nature of agency in the Anthropocene.

Competency 1: Explain the impact of human interactions with Earth's systems.

147. Elements of this competency are measured by Science Competency 1 (*Explain phenomena scientifically).* However, this competency focusses on human interactions to explore a student's understanding of human impact on Earth's systems. This competency requires both content and procedural knowledge.

148. A 15-year-old student who can explain the impact of human interactions with Earth's systems can:

1. Explain physical, living, and Earth's systems that are relevant to the environment and how they interact with each other.
2. Research and apply knowledge of human interactions with these systems over time.
3. Apply this knowledge to explain both negative and positive human impacts with these systems over time.
4. Explain how social, cultural, or economic factors contribute to these impacts.

Competency 2: Make informed decisions to act based on evaluation of diverse sources of evidence and application of creative and systems thinking to regenerate and sustain the environment.

149. This competency draws on elements that are measured by Science Competency 2 (Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically) and Science Competency 3 (Research, evaluate and use scientific

information for decision making and action). This competency requires content, procedural, and epistemic knowledge.

150. A 15-year-old student who can make informed decisions to act based on critical appraisal of diverse sources of evidence and the application of creative, systems, and intergenerational thinking to regenerate and sustain the environment can:

1. Access and critically appraise evidence from diverse ways of knowing and sources.
2. Evaluate and design potential solutions to socio-ecological issues using creative and systems thinking, taking into account implications for current and future generations.
3. Engage, individually and collectively, in civic processes to make informed, consensual decisions.
4. Set goals, collaborate with other young people and adults across generations, and act for regenerative and enduring socio-ecological change at a range of scales (local to global).

Competency 3: Demonstrate hope and respect for diverse perspectives in seeking solutions to socio-ecological crises.

151. This competency contains elements that are measured by the concept of *Science Identity*, including epistemic beliefs; dispositions of care and concern towards other people, other species, and the planet; and feelings of efficacy and agency in addressing socio-ecological crises. This competency requires content, procedural, and epistemic knowledge.

152. A 15-year-old student who uses an ethic of care and justice, and demonstrates resilience, hope, efficacy, and a respect for diverse perspectives in seeking solutions to social and environmental challenge can:

1. Evaluate actions drawing on an ethic of care for each other and all species based on a worldview where humans are part of the environment rather than separate from it (being ecocentric).
2. Acknowledge the many ways societies have created injustices and work to empower all people to contribute to community and ecosystem well-being.
3. Exhibit resilience, hope, and efficacy, individually and collectively, in responding to socio-ecological crises.
4. Respect diverse perspectives on issues and seek solutions to regenerate impacted communities and ecosystems (Reyes-Garcia, et al., 2019).

Initial Draft Reporting Scale

153. This section elaborates a draft proficiency scale based only on the cognitive elements to be measured by the Science Assessment Framework, using a four-point scale (high, medium, basic and low) shown in Table 6. The scale will be revised in the light of student performance on the field trials and actual test.

154. It should be noted that not all of the competencies of Agency in the Anthropocene defined above can be measured by the cognitive test. Instead, items from the science cognitive test that have an environmental focus and match the description of the competencies above will be used to construct a scale that is a measure of elements of

Agency in the Anthropocene. The non-cognitive attitude questionnaire will measure other elements independently.

Table 6: Initial Draft Reporting Scale proposed for the Environmental Scale in PISA 2025

Level	Descriptor
High	At a high level, students can draw effectively upon scientific ideas to explain what Earth systems are, how they function, and how they interact with each other using knowledge of high cognitive demand. They can identify and explain how human activity has had both negative and positive impacts with these Earth systems over time by accessing and critically appraising evidence from diverse knowledge systems and sources on these impacts. They can identify and explain social, cultural, and economic factors that are relevant to these impacts. Students can evaluate and suggest potential solutions to socio-ecological crises caused by human impact using their knowledge of science and systems thinking. They can explain how such solutions might impact the current and future generations. Students can provide justifications using combinations of environmental, social, cultural, and economic reasons for decisions and actions that can be taken to resolve environmental challenges.
Medium	At a medium level, students can draw upon scientific ideas to explain what Earth systems are, how they function, and/or how they interact with each other using knowledge of at least medium cognitive demand. They can identify and explain how human activity has had either negative or positive impacts within these Earth systems over time by accessing and appraising evidence from more than one knowledge system or source regarding these impacts. They can identify social, cultural, and economic factors that are relevant to these impacts. Students can evaluate and/or design potential solutions to social, environmental and ecological crises caused by human impact using their scientific knowledge and systems thinking. They can explain how such solutions might impact them and their family. Students can provide a justification, using combinations of one or two of environmental, social, cultural, and economic reasons, for decisions and actions that can be taken to resolve environmental challenges.
Basic	At a basic level, students can identify what some Earth systems are and explain how they function using knowledge of low cognitive demand. They can identify simple and common examples of how human activity has had negative or positive impacts within these Earth systems over time, using evidence from only one knowledge system or source. They can identify a limited number of social, cultural, and/or economic factors that are relevant to these impacts. They can suggest one potential solution to a social, environmental and /or ecological crisis caused by human impact using systems thinking. They can explain how such solutions might impact them. Students can provide a simple justification, using one of environmental, social, cultural, or economic reasons, for decisions and actions that can be taken to resolve environmental challenges.
Low	At a low level, students can identify an Earth system and explain how it functions using knowledge of low cognitive demand. They can identify a simple or common example of how human activity has had negative or positive impacts within this Earth system over time. They can justify this using one piece of evidence. They can identify a social, cultural, and/or economic factor that is relevant to its impact. They can suggest one potential solution to an environmental crisis caused by human impact using systems thinking. They can explain how such a solution might impact them. Students can provide a simple justification, using one environmental, social, cultural, or economic reason, for a decision and action that can be taken to resolve an environmental challenge.

Assessment for the Environmental Scale

155. This scale will be constructed using content, procedural and epistemic knowledge questions in the science framework that are clearly related to any science that can be considered to be of an environmental or ecological nature. A similar assessment of environmental competence was done in 2006 for the "Green at Fifteen Project". Because of the cognitive focus of the science test, it will only be possible to measure Competency 1 and Competency 2. To measure this construct fully, however, it will also be necessary to ask questions about the following – elements of which will be asked in the non-cognitive questionnaire:

- The science needed to respond to claims made about environmental/health made by people or interest groups on the bases of other values/knowledges (e.g. responding to a person who refuses vaccination on the basis that there's a percentage of people who develop serious side effects, or who argues that a number of vaccinated people have died)
- Identifying the science knowledge, including possible investigations, relevant for responding to different positions on environmental/health actions, including deciding on personal actions (e.g. identifying the science research needed to respond to the different concerns of farmers concerned about re-introduction of top predators into a local national park, or in deciding about culling introduced species such as brumbies – the question might for instance involve a matching of science investigations with a list of concerns or claims)

- Identifying which of different positions in an environmental controversy are scientifically based, and which are based on other knowledges and values.
- Weighing different alternatives given the science knowledge relevant to a personal or community health/environmental issue e.g. should I use plastic cups in catering for a large party, or glass cups and wash them in a dishwasher – the science would relate to the energetics of dishwashing, water and detergent use, recycling figures on plastic etc – it might simply ask which ideas are relevant for the decision
- Identifying the socio-ecological considerations that legitimately frame scientific research in an area (e.g. in scientific developmental research into mobile phones technical design, which issues might be expected to frame decisions, and what sort of principles are involved (economic, cultural, ethical, environmental), from a list – the sourcing of rare metals from exploitative practices, the costs of extraction, the possibility of recycling of materials, the advertising campaign associated with the phone, the opinion of uses on phone colour)
- Predicting the consequences across different parts of the socio-ecological system that would flow from particular decisions e.g. given a mapping of a complex system relating to an aquifer used by a population in multiple ways but increasingly contaminated by pesticide use by agriculture on which the community depends for food and livelihood, predict what environmental consequences might flow from a particular decision related to water use, or pesticide use, that might depend on knowing the pathways through related economic/recreational systems leading back to environmental impact.

7. Sample Items

156. In this section, nine examples of science units are presented. Questions from the unit are shown in the manner they might be transposed and presented on screen.

Science Example 1: Greenhouse

157. Science example 1 is titled GREENHOUSE and deals with the increase of the average temperature of the Earth’s atmosphere. The stimulus material consists of a short text introducing the term “Greenhouse effect” and includes graphical information on the average temperature of the Earth’s atmosphere and the carbon dioxide emission on the Earth over time.

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

PISA 2025

Greenhouse 1

THE ENHANCED GREENHOUSE EFFECT: FACT OR FICTION?

The energy that sustains most living things on Earth comes from the sun's radiation. The Earth's atmosphere acts like a protective blanket around our planet, allowing the sun's radiation to pass through and absorbing some of the energy radiated back from Earth that would otherwise escape.

As a result of this, the average temperature of the Earth's atmosphere is higher than it would be if there were no atmosphere to trap the heat energy. The Earth's atmosphere thus has a similar effect to a greenhouse where the glass of the greenhouse traps heat energy from the sun and keeps the inside warm.

The data indicate that the average temperature of the Earth's atmosphere has significantly increased over the last century. The reason for this average temperature increase is said to be because of increased atmospheric carbon dioxide, which causes the atmosphere to more effectively trap heat – the greenhouse effect is thus enhanced by CO_2.

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

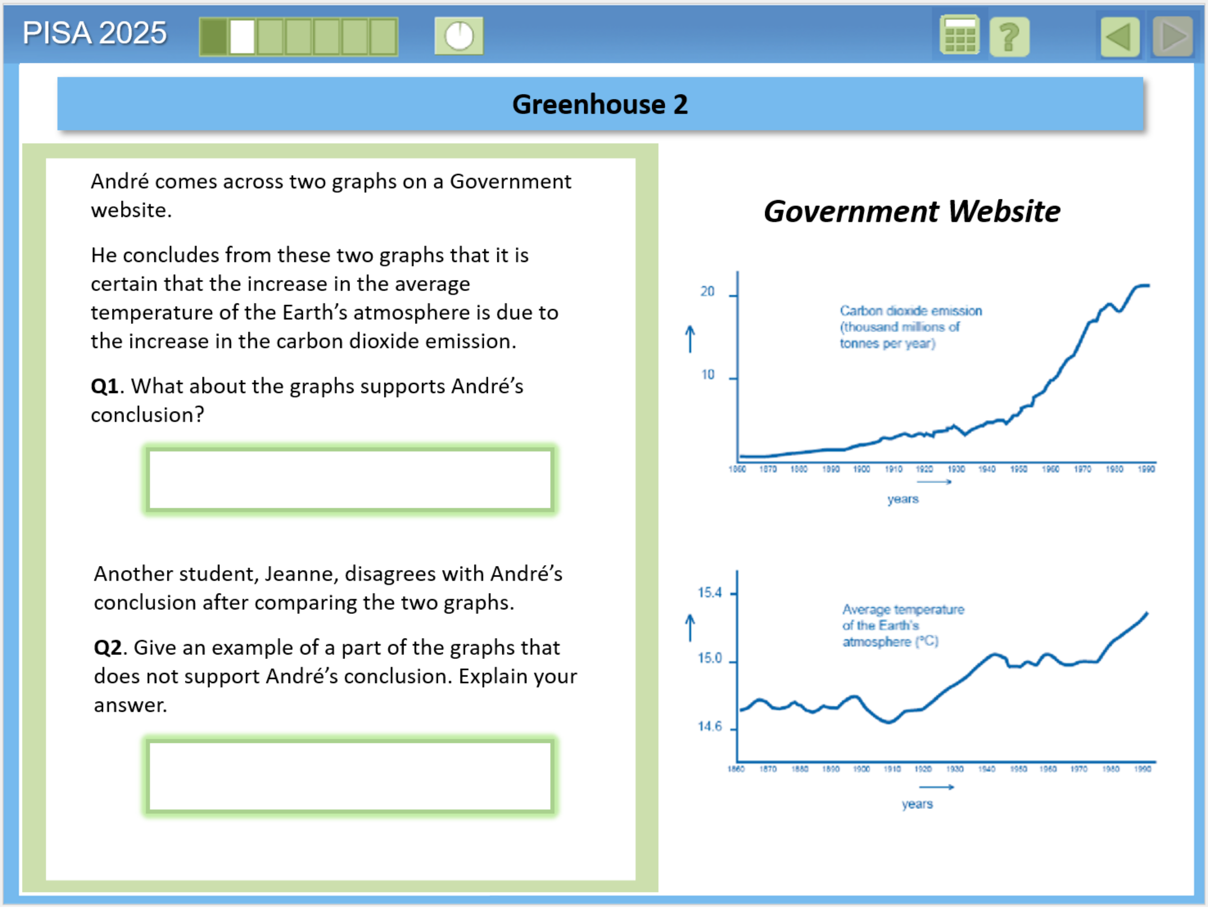


Table 7: Framework categorisation for GREENHOUSE Question 1

Framework categories	2025 Framework
Knowledge type	Procedural
Competency	Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically
Context	Environmental, Global
Cognitive demand	Medium

159. Question 1 requires students to understand the data is represented in the two graphs and construct an interpretation of their meaning. This question requires an interpretation of graphs involving a few linked steps. The question is categorised as medium cognitive.

Table 8: Framework categorisation for GREENHOUSE Question 2

Framework categories	2025 Framework
Knowledge type	Procedural
Competency	Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically
Context	Environmental, Global
Cognitive demand	Medium

160. Question 2 also requires students to understand the data is represented in the two graphs and construct an interpretation of their meaning. This question requires an interpretation of graphs involving a few linked steps. The question is categorised as medium cognitive though is a bit more demanding as it requires identify a specific feature of the graph.

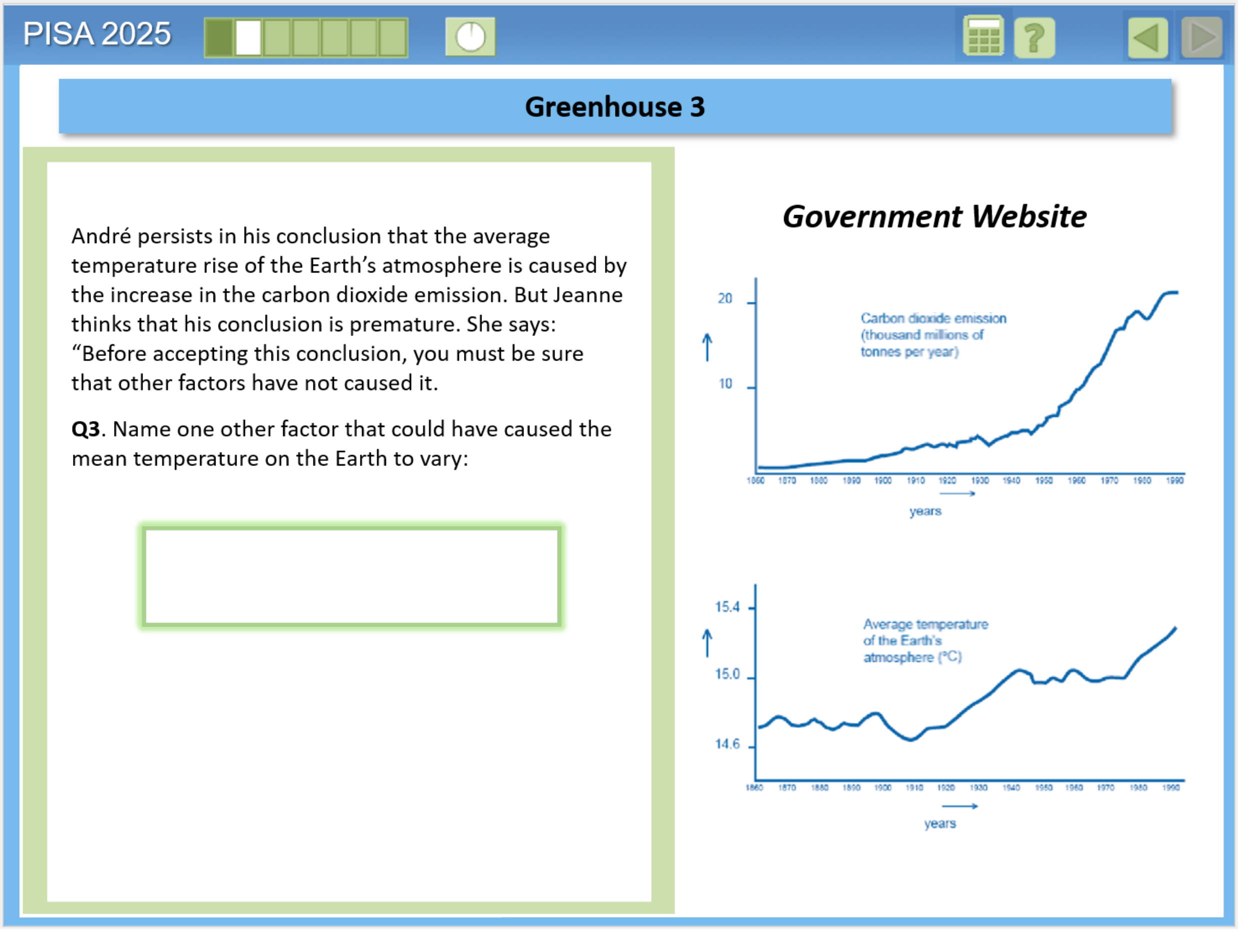


Table 9: Framework categorisation for GREENHOUSE Question 3

Framework categories	2025 Framework
Knowledge type	Content
Competency	Explain Phenomena Scientifically
Context	Environmental, Global
Cognitive demand	Low

161. Question 3 requires students to use scientific knowledge to provide an alternative factor which might explain global warming. This question is considered to be of medium cognitive demand.

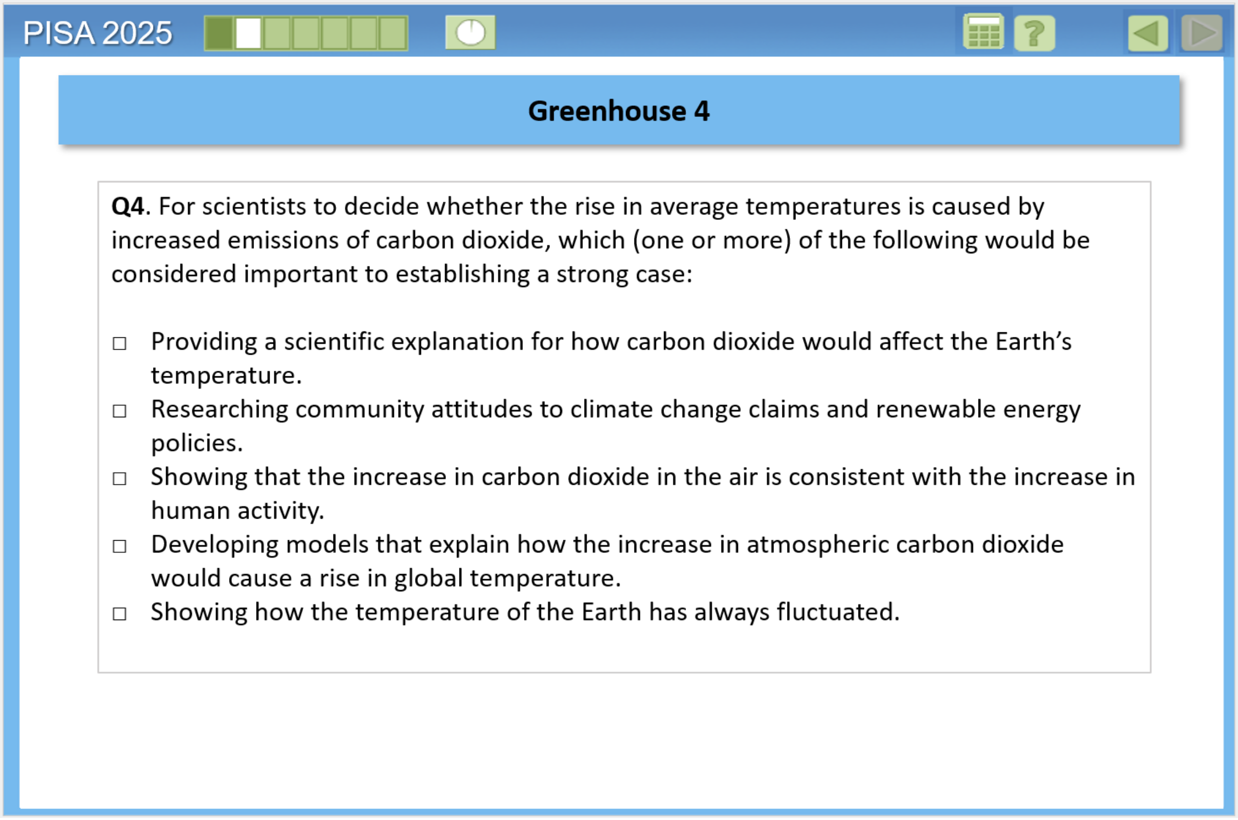


Table 10: Framework categorisation for GREENHOUSE Question 4

Framework categories	2025 Framework
Knowledge type	Epistemic
Competency	Research, evaluate and use scientific information for decision making and action
Context	Environmental, Global
Cognitive demand	High

162. Question 4 requires students to draw on their epistemic knowledge to make a judgement about the nature of scientific evidence and which is most important in constructing an argument. The question is categorised as being of high cognitive demand.

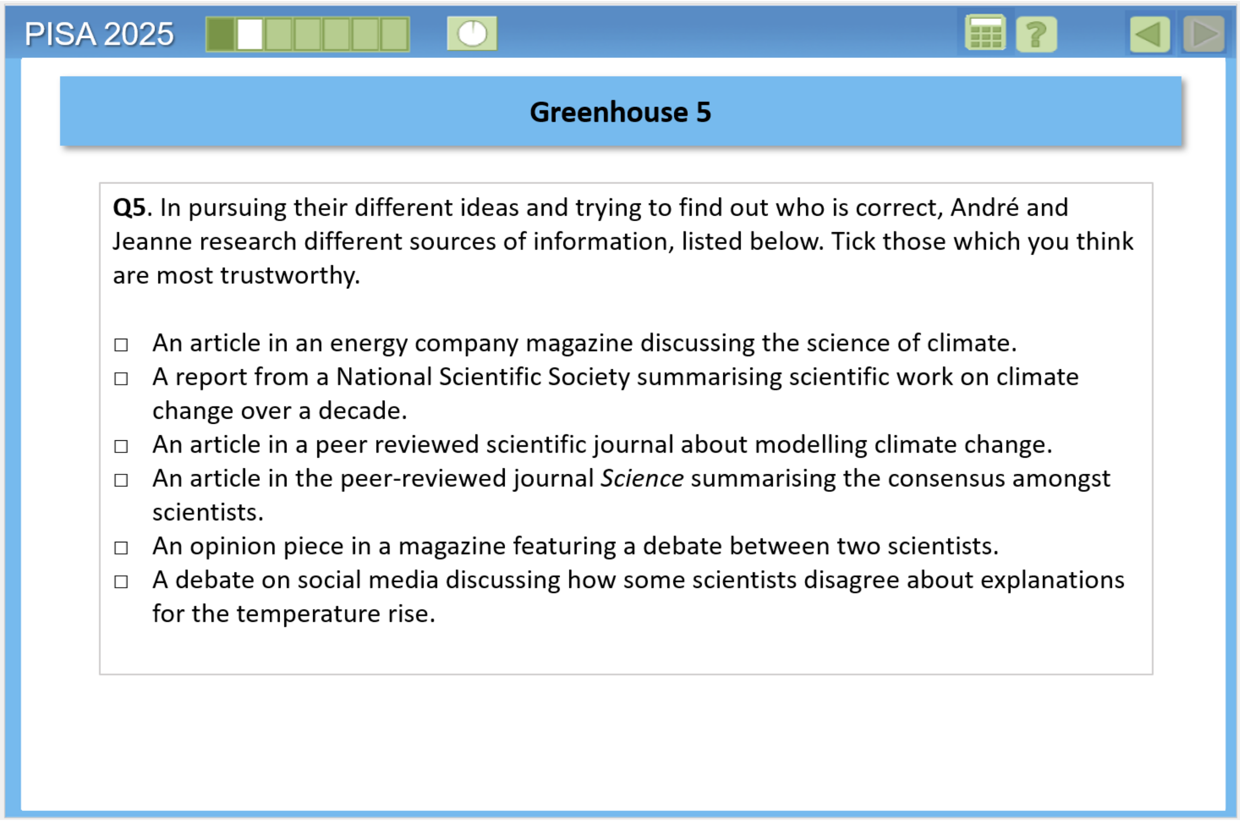


Table 11: Framework categorisation for GREENHOUSE Question 5

Framework categories	**2025 Framework**
Knowledge type	Epistemic
Competency	Research, evaluate and use scientific information for decision making and action
Context	Environmental, Global
Cognitive demand	Medium

163. Question 5 requires students to draw on their epistemic knowledge to make a judgement about the nature of scientific evidence and which is most trustworthy in constructing an argument. The question is categorised as being of high cognitive demand.

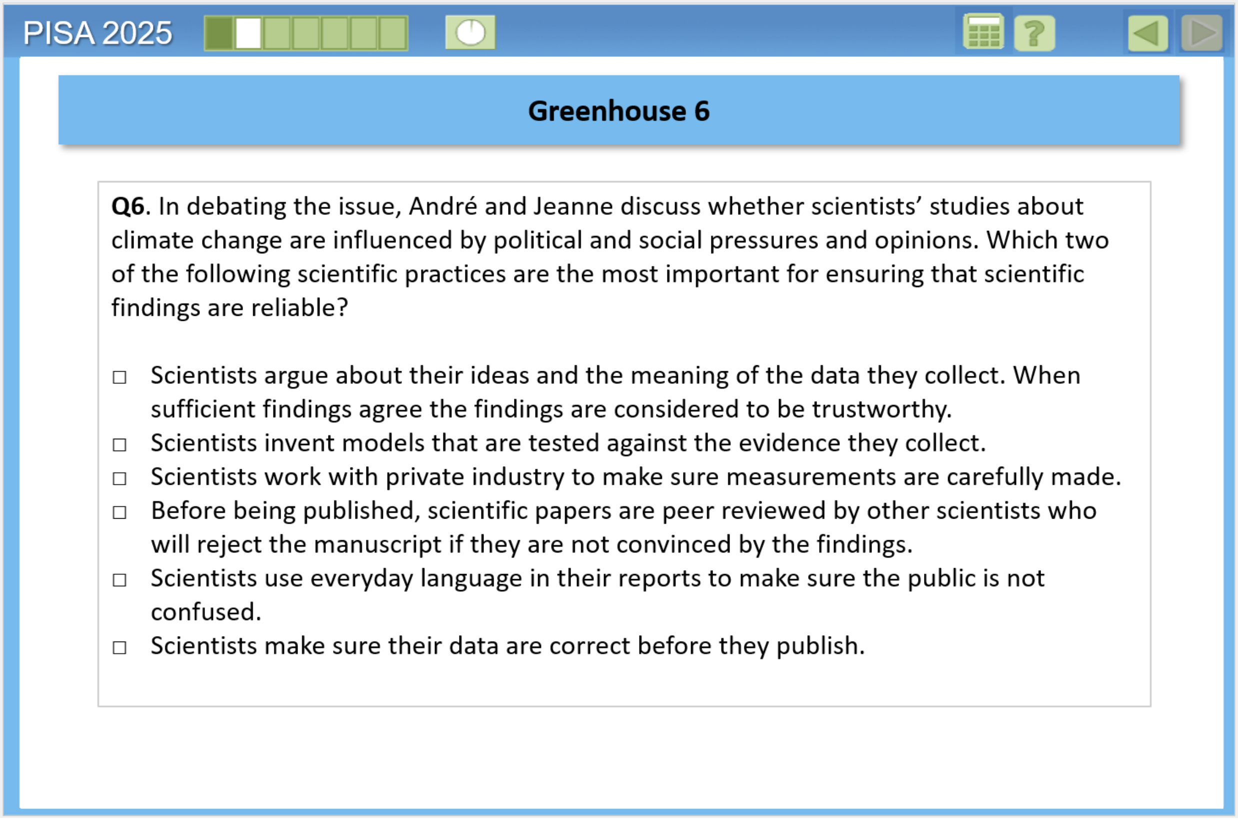


Table 12: Framework categorisation for GREENHOUSE Question 6

Framework categories	2025 Framework
Knowledge type	Epistemic
Competency	Research, evaluate and use scientific information for decision making and action
Context	Environmental, Global
Cognitive demand	High

164. Question 6 requires students to draw on their epistemic knowledge to make a judgement about the nature of scientific evidence and which is most trustworthy in constructing an argument. The question is categorised as being of high cognitive demand.

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

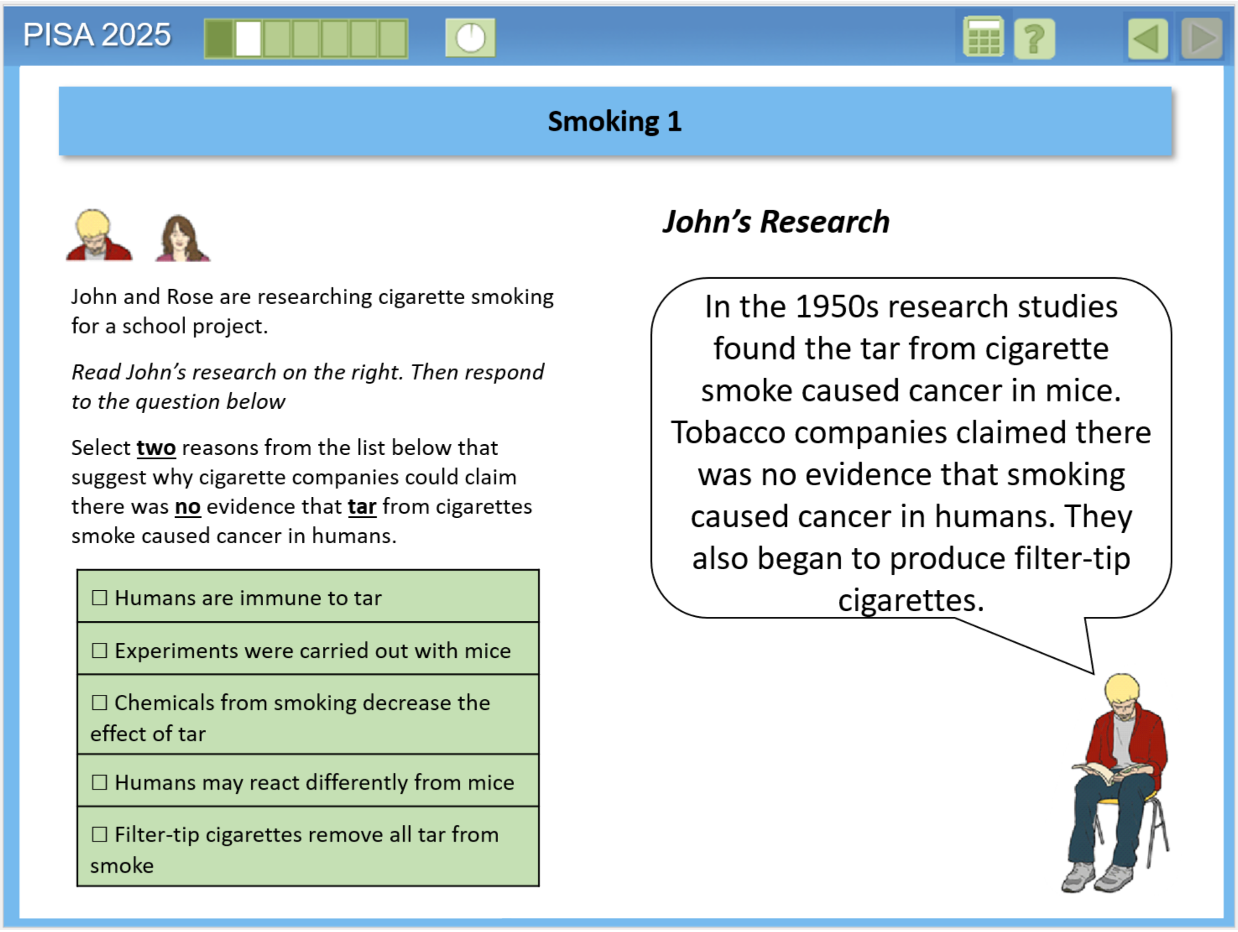
Science Example 2: Smoking

166. This 2015 exemplar unit explores various forms of evidence linked to the harmful effects of smoking and the methods used to help people to stop smoking. New Science items for 2025 will only be developed for computer-based delivery and therefore this exemplar is only shown in an onscreen format.

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

SMOKING: question 1

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



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

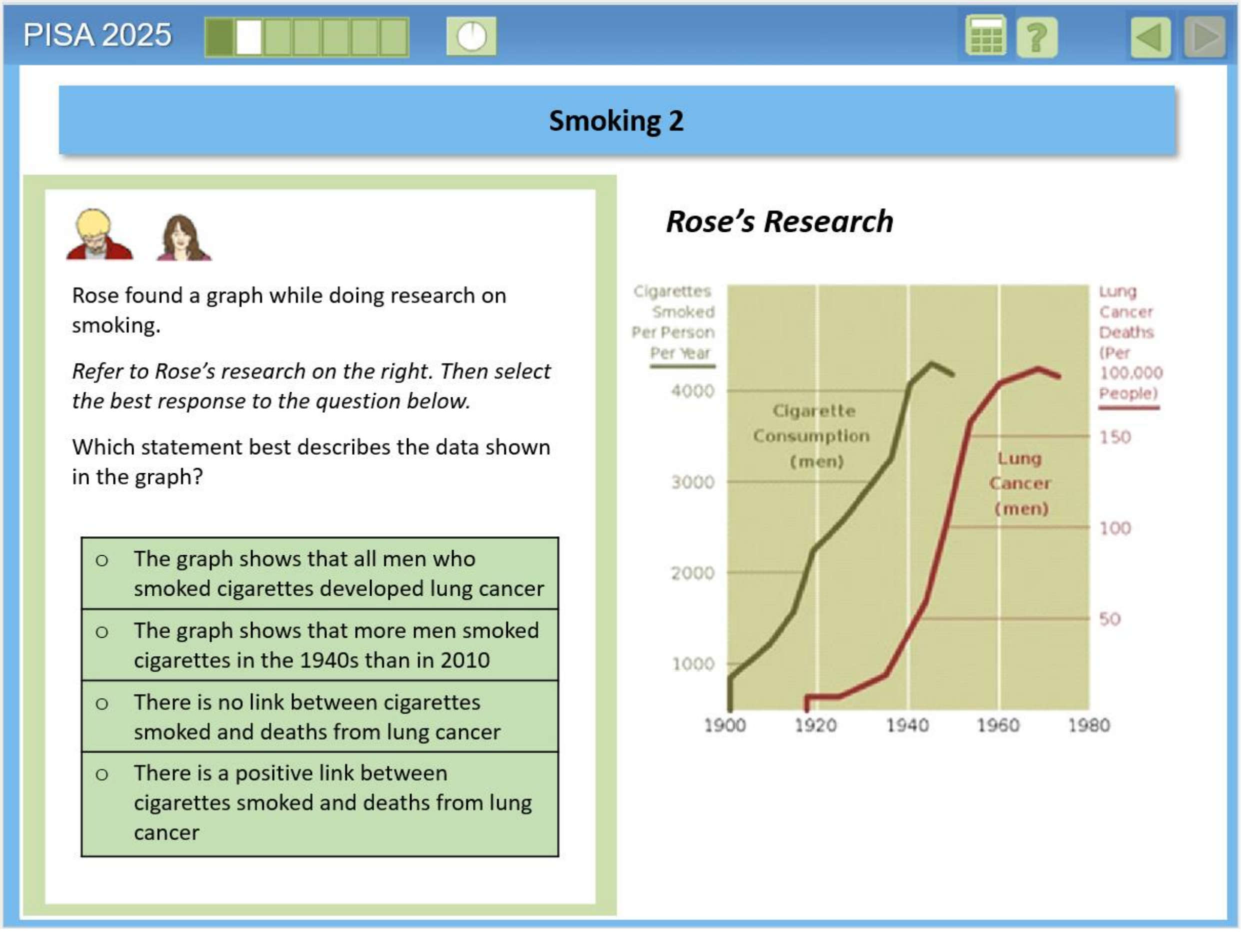
Table 13: Framework categorisation for SMOKING question 1

Framework categories	2025 Framework
Knowledge type	Content
Competency	Explain phenomena scientifically
Context	Health and Disease, Local/National
Cognitive demand	Medium

SMOKING: question 2

170. This question explores students’ understanding of data.

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



172. This unit tests content knowledge using the competency of construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically.

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

Table 14: Framework categorisation for SMOKING question 2

Framework categories	2025 Framework
Knowledge type	Procedural
Competency	Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically
Context	Health and Disease Local/National
Cognitive demand	Medium

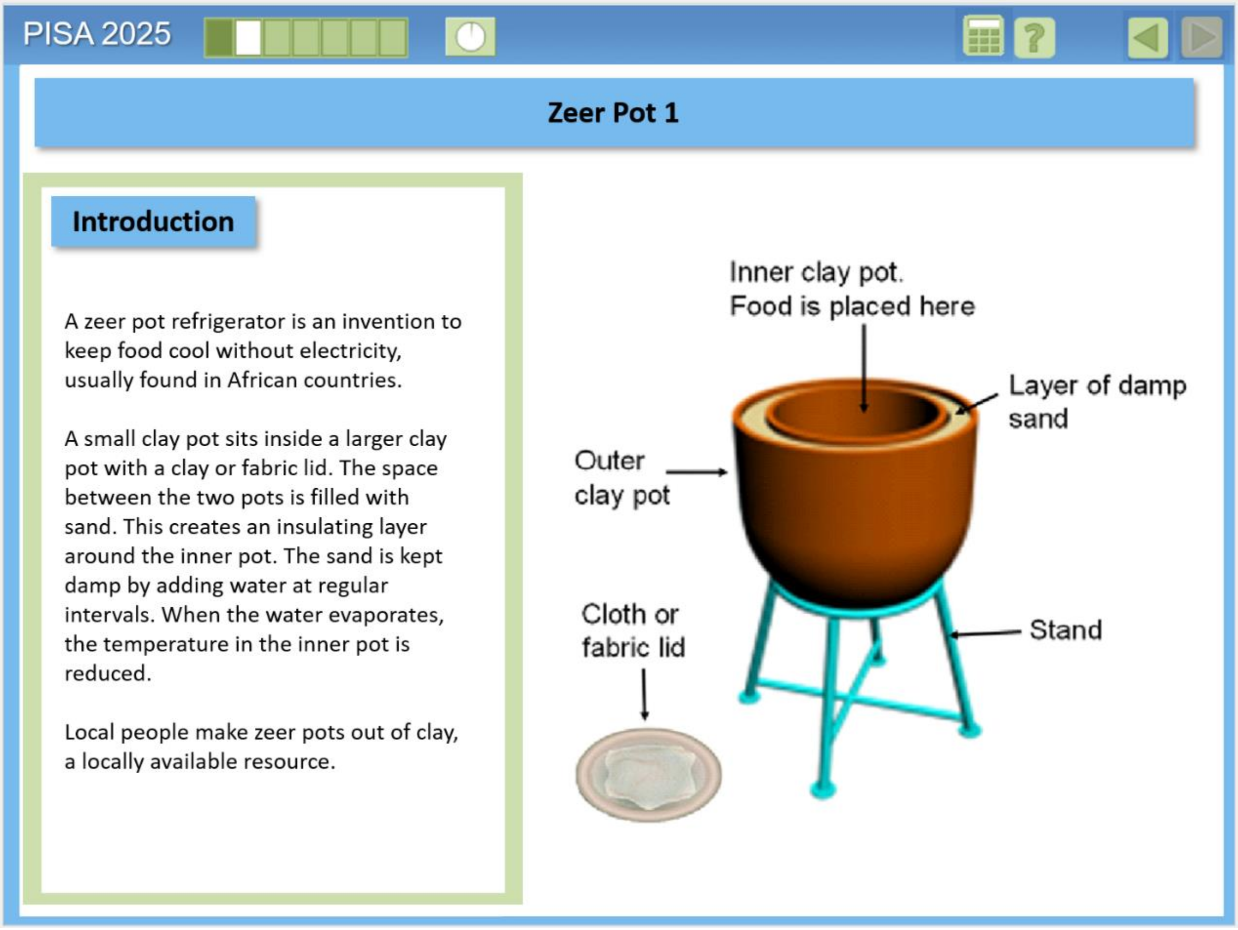
Science Example 3: Zeer pot

174. This 2015 exemplar unit demonstrates a new feature of science assessment that was used in 2015; the use of interactive tasks using simulations of scientific enquiry to explore and assess scientific knowledge and competencies.

175. This unit is focussed on an authentic low-cost cooling container called a Zeer pot, developed for localised needs in Africa, using readily available local resources. Cost and lack of electricity limits the use of refrigerators in these regions, while the hot climate necessitates food to be kept cool to prolong the length of time food can be kept before bacterial growth renders it a risk to health.

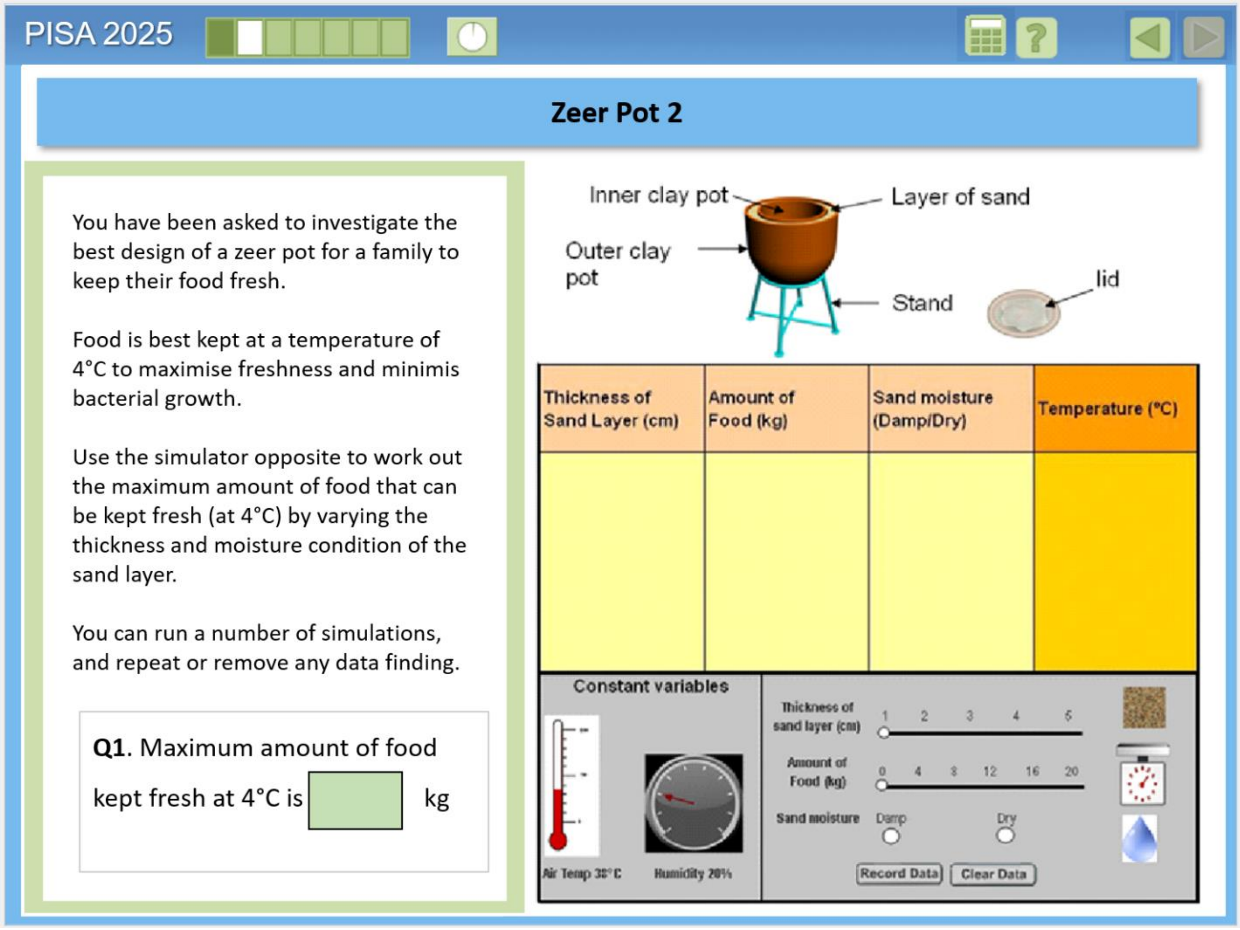
176. The first screenshot of this simulation introduces what a Zeer pot looks like and how it works. Students are not expected to understand how the process of evaporation causes cooling, just that it does. The reader will notice the following revisions since the first draft presented to the PGB prior to the 45th meeting in April 2018:

ZEER POT: stimulus



177. Using this simulation, students are asked to investigate the conditions that will produce the most effective cooling effects (4 0C) for keeping food fresh in the Zeer pot. The simulator keeps certain conditions constant (the air temperature and the humidity) but includes this information to enhance the authentic contextual setting. In the first question, students are asked to investigate the optimum conditions to keep the maximum amount of food fresh in the Zeer pot by altering the thickness of the sand layer and the moisture conditions.

ZEER POT: Question 1



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

179. The knowledge categorisation for this item is procedural and the competence is ‘Evaluate designs for scientific enquiry and interpret scientific data and evidence critically’. The context categorisation is Natural Resources, although it also has links to Health and Disease. The cognitive demand of this question is categorised as high because students are given a complex situation, and they need to develop a systematic sequence of investigations to answer the question.

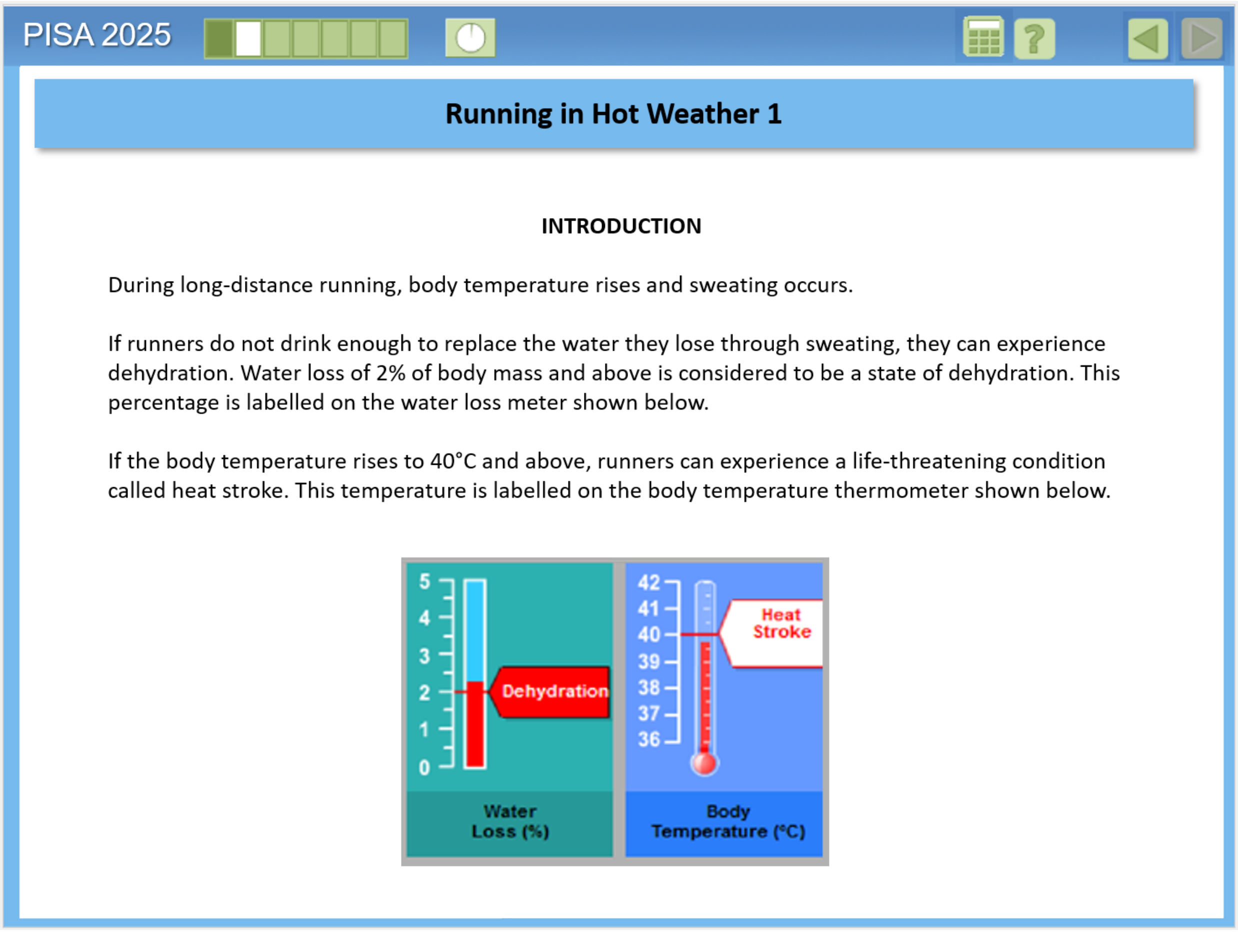
Table 15: Framework categorisation for ZEER POT question 1

Framework categories	2025 Framework
Knowledge type	Procedural
Competency	Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically
Context	Natural Resources
Cognitive demand	High

Science Example 4: Running in Hot Weather

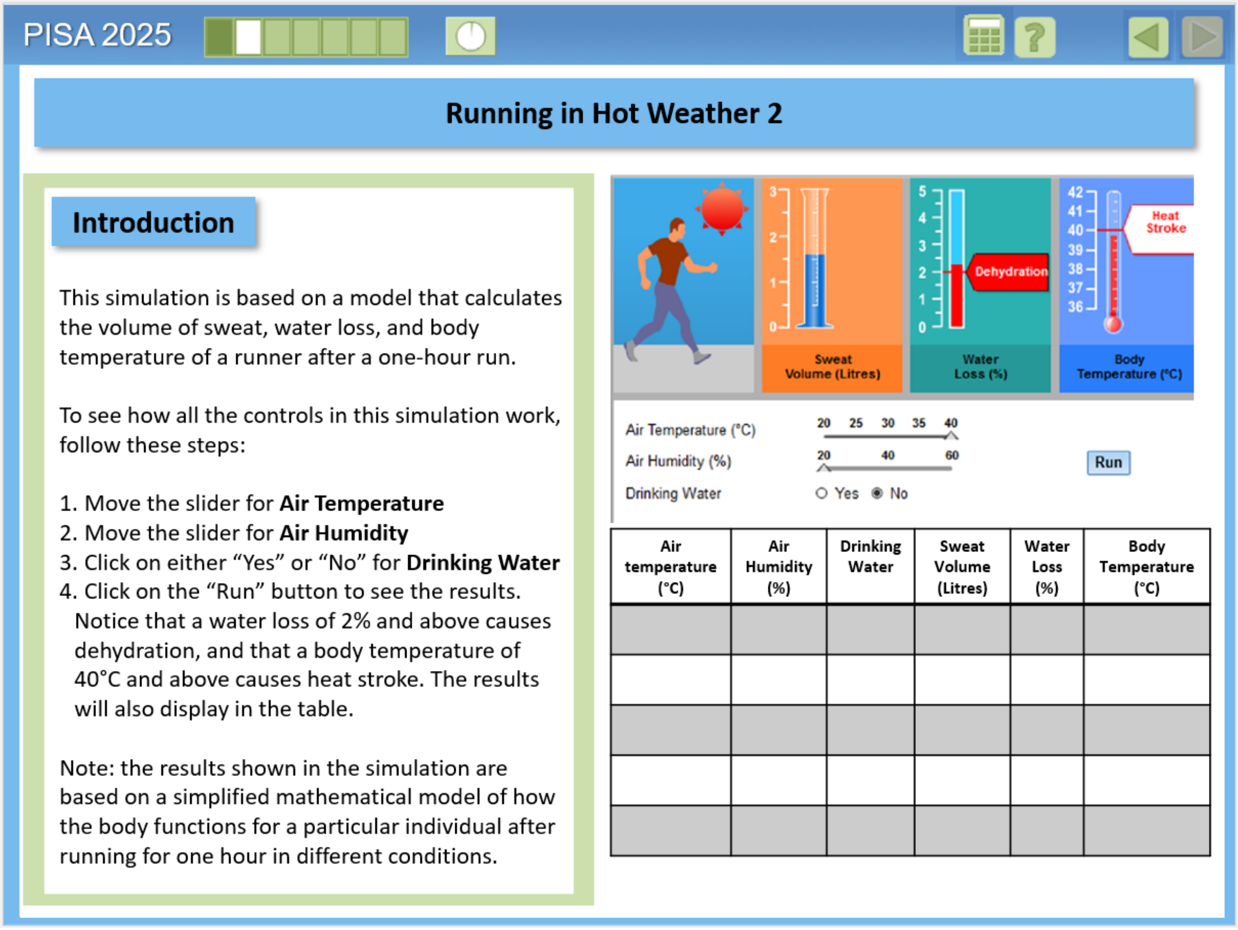
180. This unit presents a scientific enquiry about thermoregulation in the context of long-distance runners training in a location where weather conditions are sometimes hot and/or humid. The simulation allows students to manipulate the air temperature and air humidity levels, as well as whether or not the simulated runner drinks water. For each trial, data associated with the selected variables are displayed, including: air temperature, air humidity, drinking water (yes/no), sweat volume, water loss and body temperature. The runner's sweat volume, water loss and body temperature are also displayed on the top panel in the simulation panel. When the conditions trigger dehydration or heat stroke those health dangers are highlighted with red flags.

RUNNING IN HOT WEATHER: Stimulus



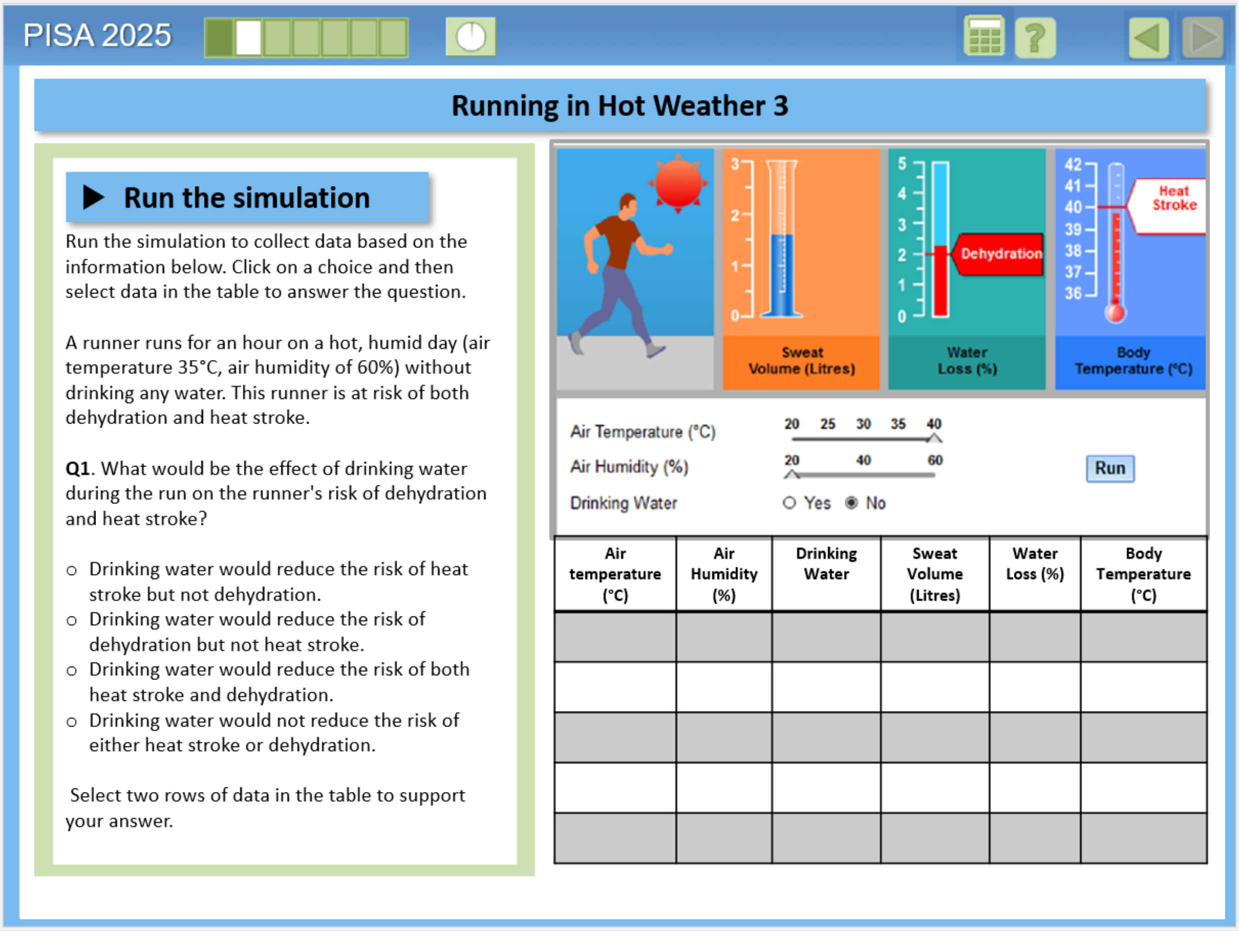
181. Before beginning the unit, students are introduced to the simulation controls and asked to practice setting each control. Help messages are displayed if students do not perform the requested actions within 1 minute. If students time-out by not acting within 2 minutes, they are shown what the simulation would look like if the controls were set as specified in the provided instructions. As explained in the orientation that students take before beginning the Science section, reminders about how to use the controls, as well as how to select or delete a row of data are available on each question screen by clicking on the "How to Run the Simulation" tab in the left pane.

RUNNING IN HOT WEATHER: Stimulus



182. In this question, students are provided with the specific values for each of the variables in the simulation. They must set the controls as specified and run the simulation once. A red flag is displayed indicating that, under these conditions, the runner would suffer from water loss leading to dehydration. This is the easiest question in the unit, requiring students to carry out a straightforward procedure, identify the flagged condition in the display as shown below, and interpret the display to correctly identify water loss as the cause of the runner's dehydration.

RUNNING IN HOT WEATHER: Question 1



183. There are a further 4 questions of this nature in this simulation. The full simulation can be found at: http://www.oecd.org/pisa/PISA2015Questions/platform/index.html?user=&domain=SCI&unit=S623-RunningInHotWeather&lang=eng-USA

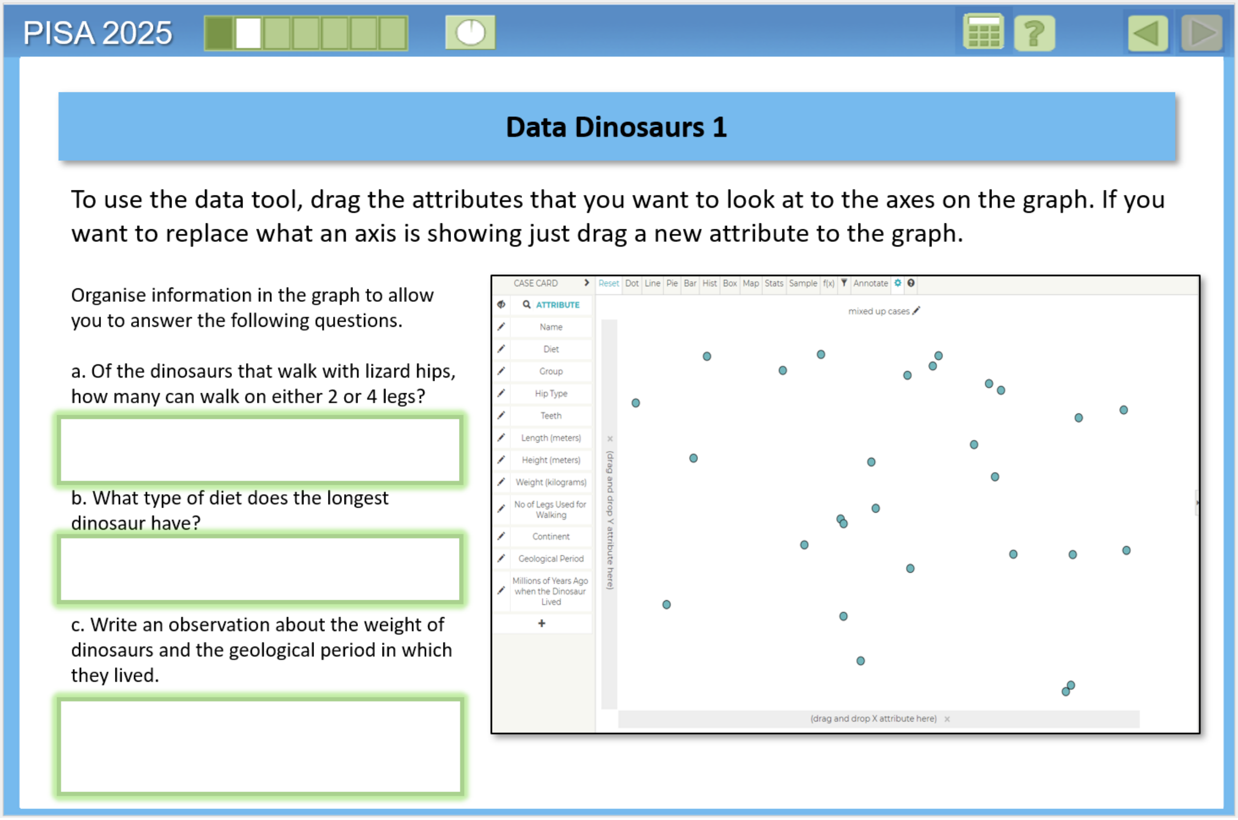
Table 16: Framework categorisation for RUNNING IN HOT WEATHER question 1

Framework categories	2025 Framework
Knowledge type	Procedural
Competency	Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically
Context	Health and Disease
Cognitive demand	Medium

Science Example 5: Data Dinosaurs

184. In this question, students are presented with a set of data on dinosaurs. The tool allows them to plot one category against another to search for patterns in the data. The question tests their ability to determine which data sets should be identified and plotted to answer the questions posed

DATA DINOSAURS: Question 1



185. The second question presents them with a graph of the data and asks them to evaluate the conclusion critically.

DATA DINOSAURS: Question 2

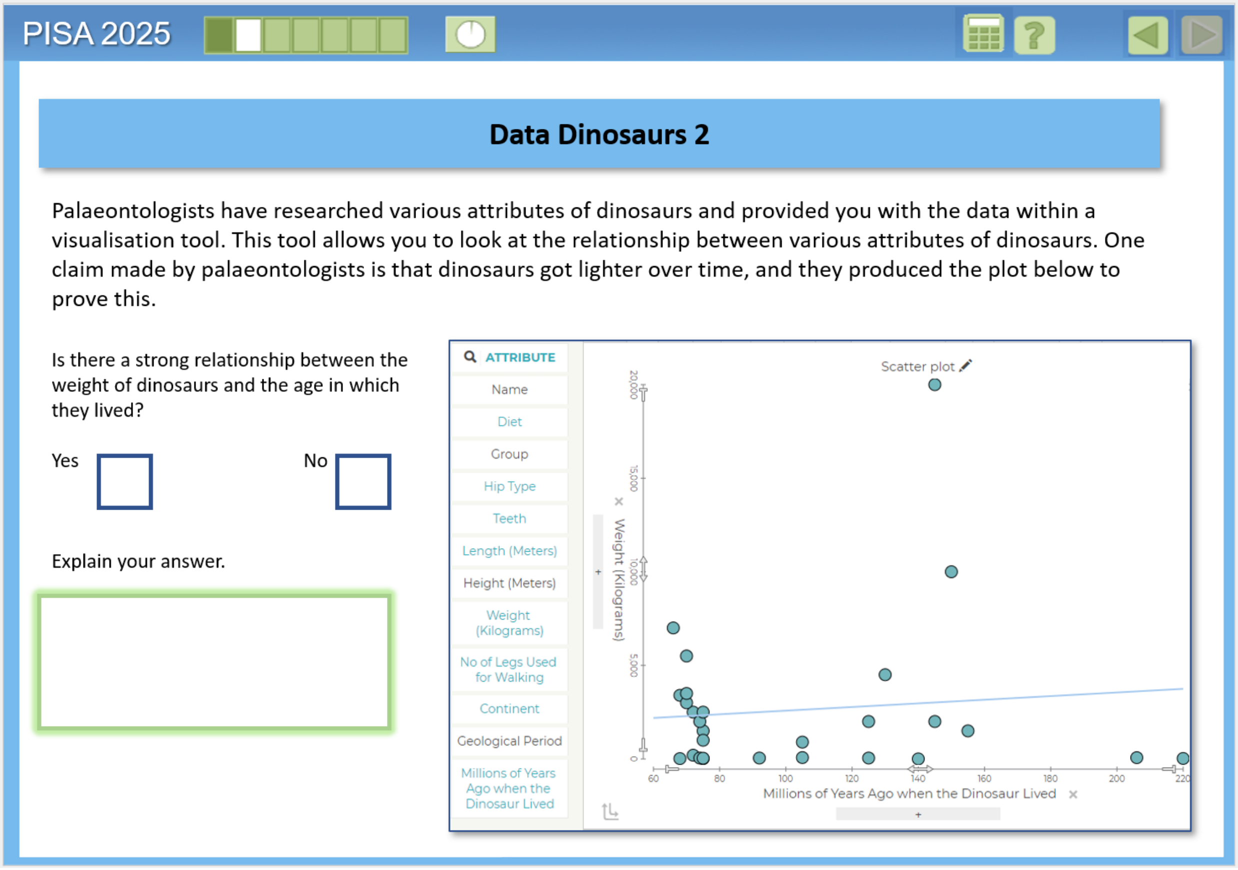


Table 17: Framework categorisation for DATA DINOSAURS question 2

Framework categories	2025 Framework
Knowledge type	Procedural
Competency	Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically
Context	Contemporary Scientific and Technological Issues (Global)
Cognitive demand	Medium

Science Example 6: The Dangers of Smoking

186. In this Question, students are asked to use epistemic knowledge to assess which types of evidence best support a claim.

DANGERS OF SMOKING: Question 1

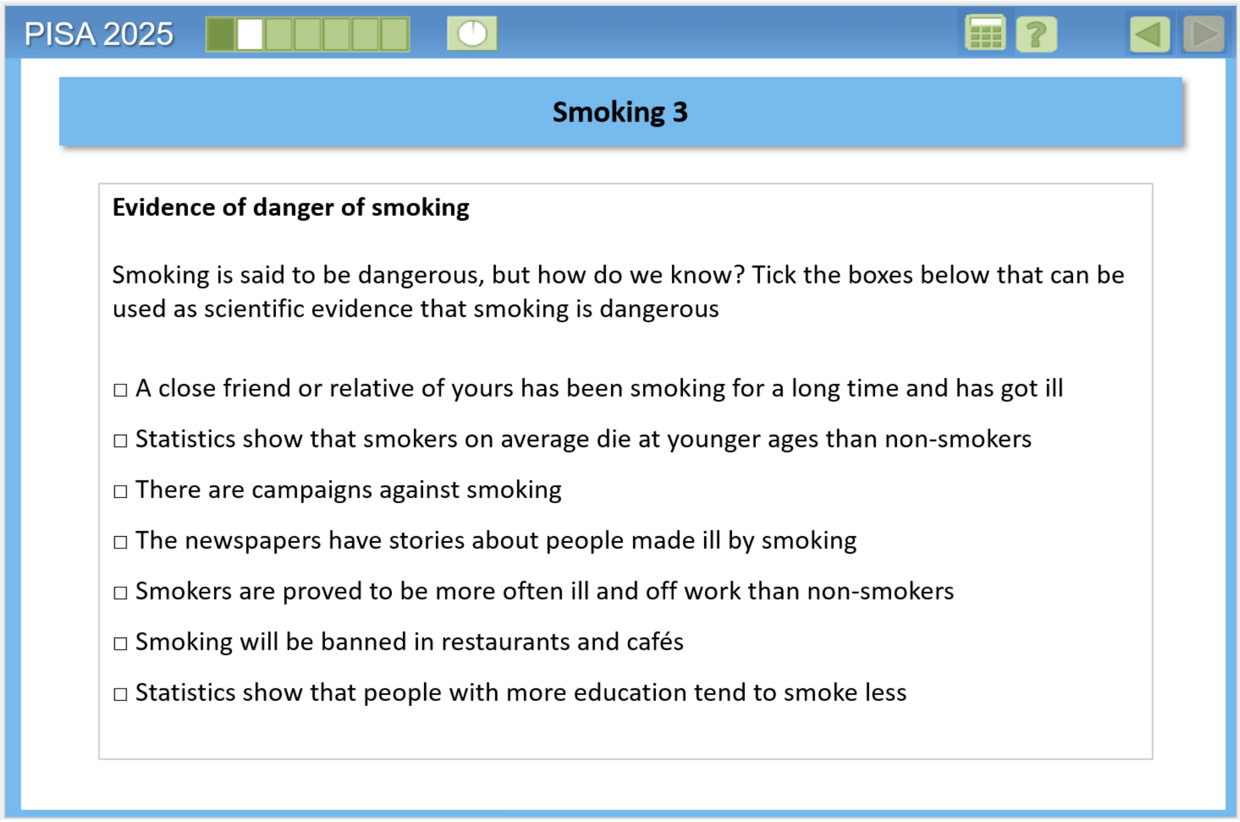


Table 19: Framework categorisation for DANGERS OF SMOKING question

Framework categories	2025 Framework
Knowledge type	Epistemic
Competency	Research, evaluate and use scientific information for decision making and action
Context	Health Hazards (Global)
Cognitive demand	Medium

Science Example 7: Who should we believe?

187. The following question is an example of the kind of question that might be used to test epistemic knowledge.

WHO SHOULD WE BELIEVE? Question 1

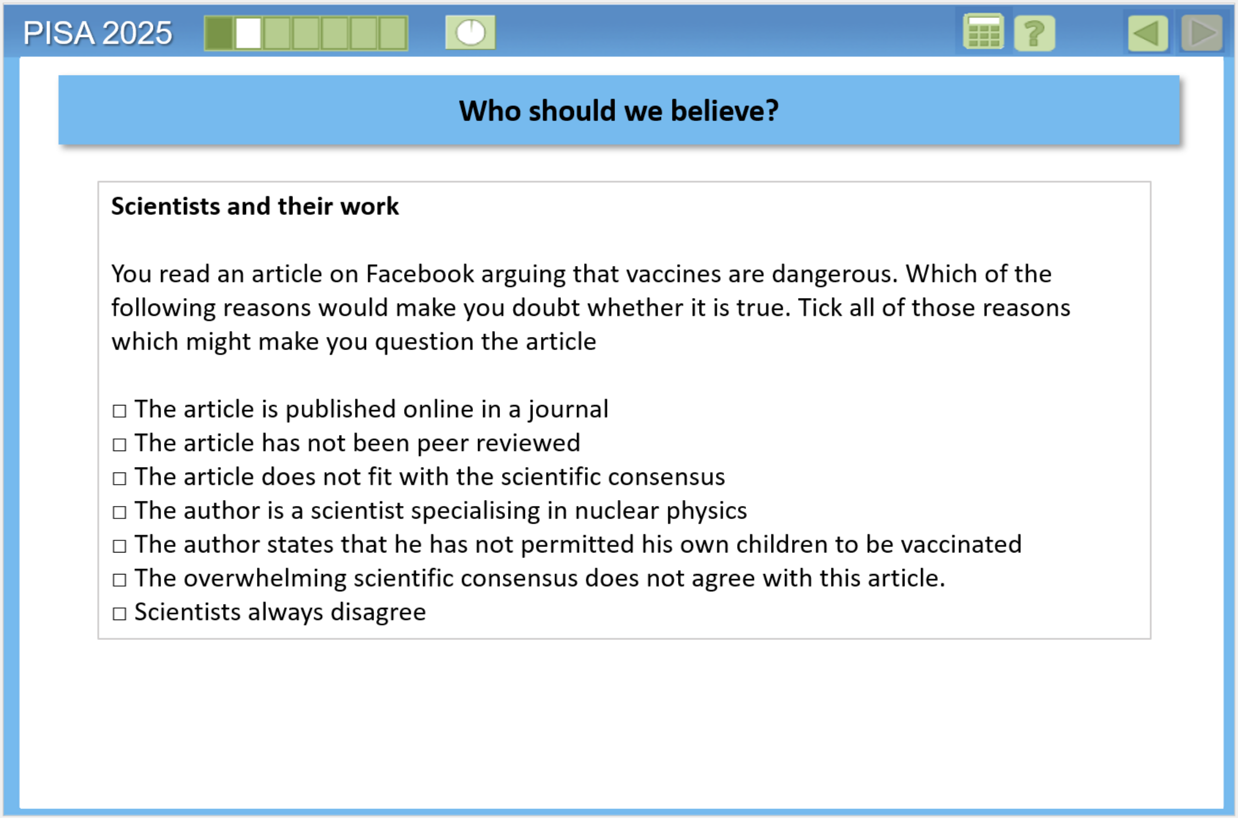


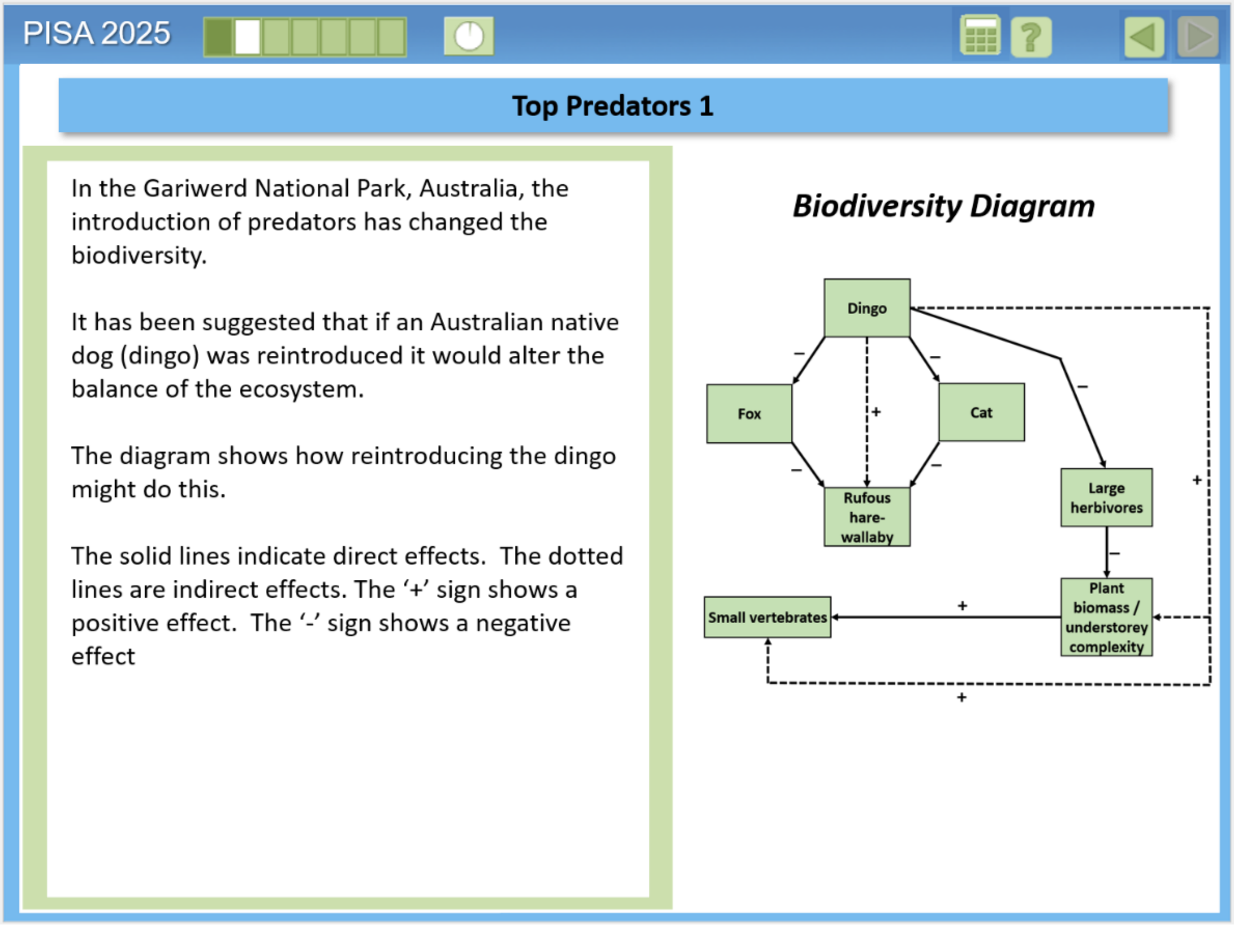
Table 20: Framework categorisation for WHO SHOULD WE BELIEVE question

Framework categories	2025 Framework
Knowledge type	Epistemic
Competency	Research, evaluate and use scientific information for decision making and action
Context	Health Hazards (Global)
Cognitive demand	Medium

Science Example 8: Top Predators

188. The following question is an example of the kind of question that might be used to test the socio-ecological knowledge required for Agency in the Anthropocene.

TOP PREDATORS: Stimulus



TOP PREDATORS: Question 1 & 2

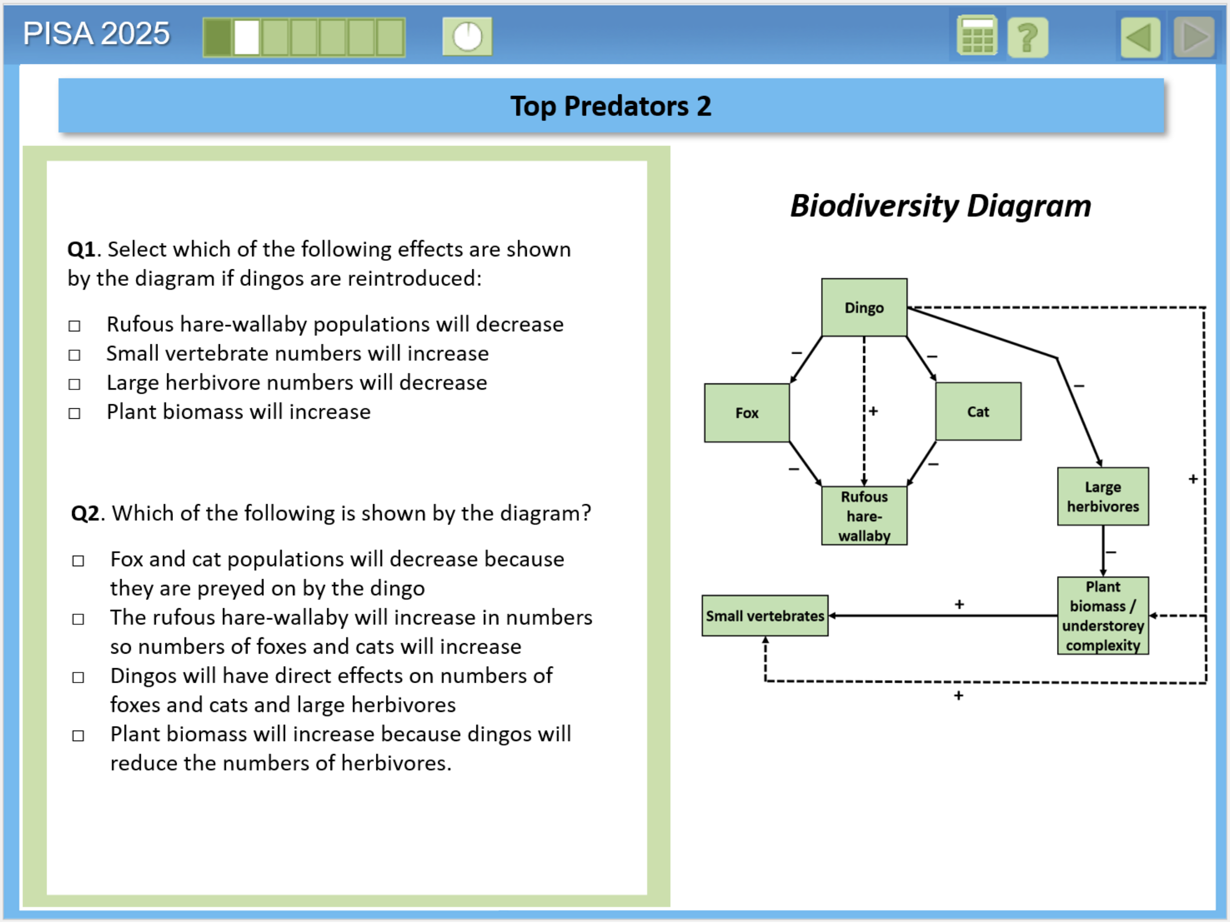


Table 21: Framework categorisation for TOP PREDATORS Question 1

Framework categories	2025 Framework
Knowledge type	Content
Competency	Explain Phenomena Scientifically
Context	Environmental Impacts & Climate Change (Local)
Cognitive demand	Medium

Table 22: Framework categorisation for TOP PREDATORS Question 2

Framework categories	2025 Framework
Knowledge type	Content
Competency	Explain Phenomena Scientifically
Context	Environmental Impacts & Climate Change (Local)
Cognitive demand	Low

TOP PREDATORS: Question 3

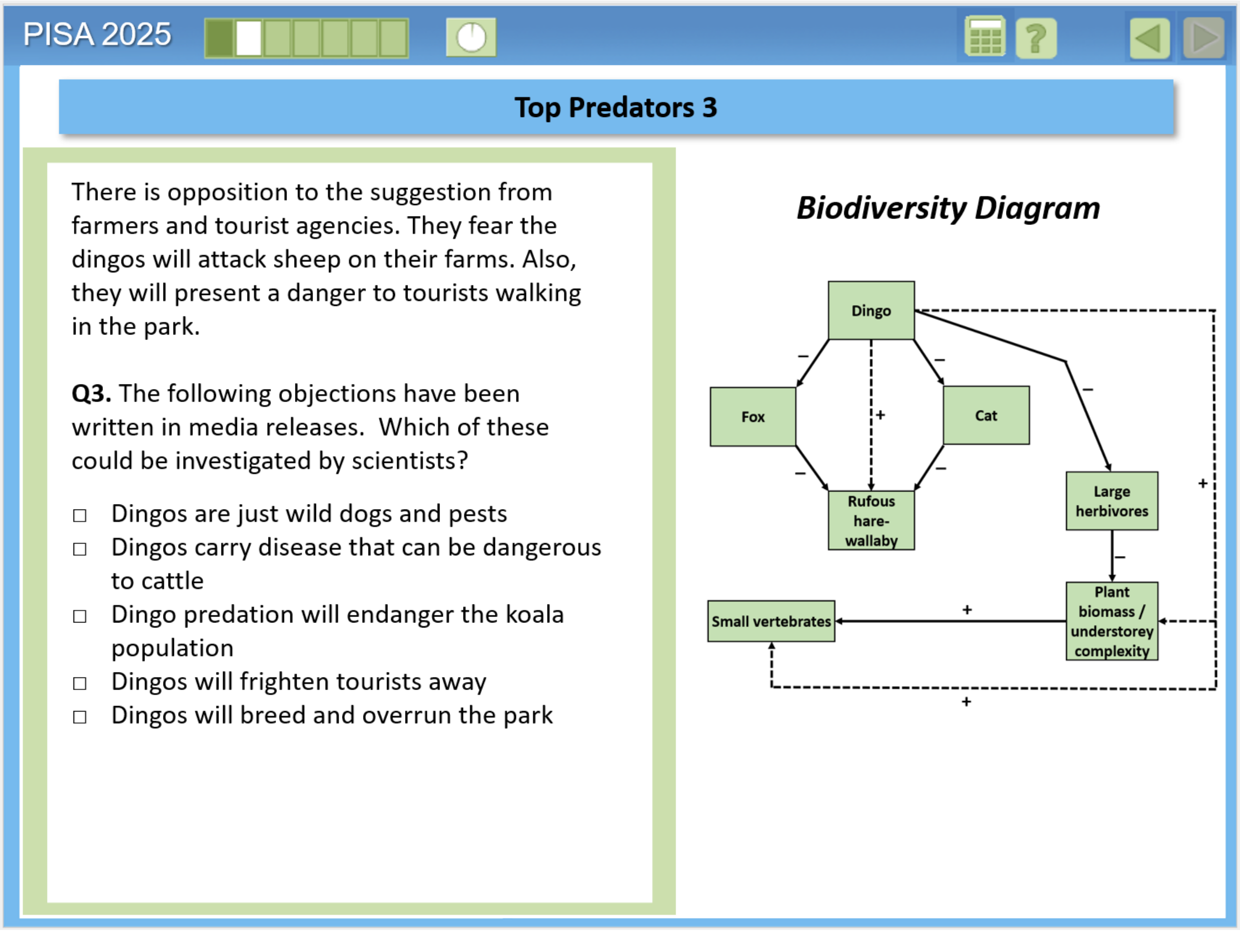


Table 23: Framework categorisation for TOP PREDATORS Question 3

Framework categories	2025 Framework
Knowledge type	Epistemic & Content
Competency	Research, Evaluate & Use Information for Decision Making and Action
Context	Environmental Impacts & Climate Change (Local)
Cognitive demand	Medium

TOP PREDATORS: Question 4

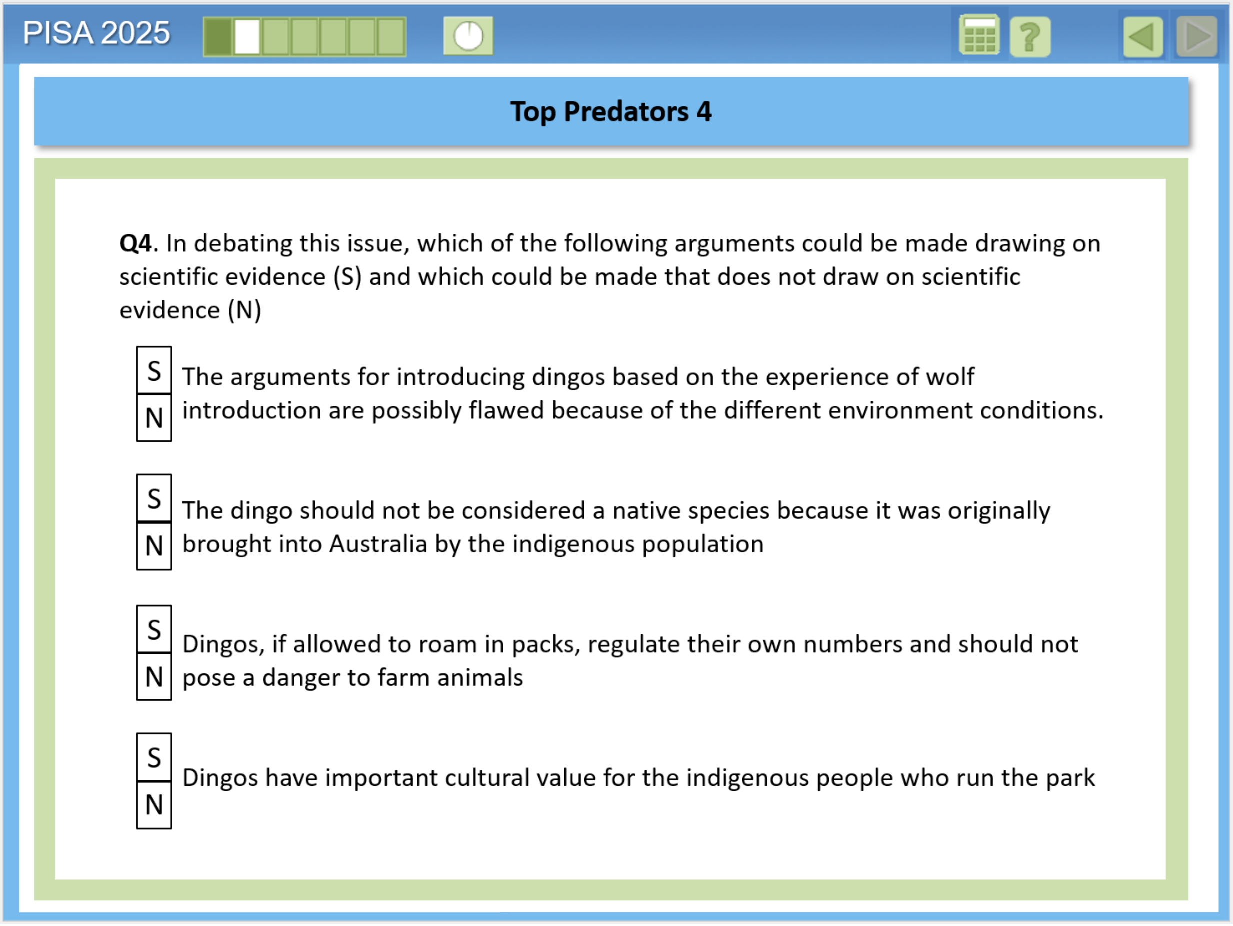


Table 24: Framework categorisation for TOP PREDATORS Question 4

Framework categories	2025 Framework
Knowledge type	Epistemic
Competency	Research, Evaluate & Use Information for Decision Making and Action
Context	Environmental Impacts & Climate Change (Local)
Cognitive demand	High

TOP PREDATORS: Question 5

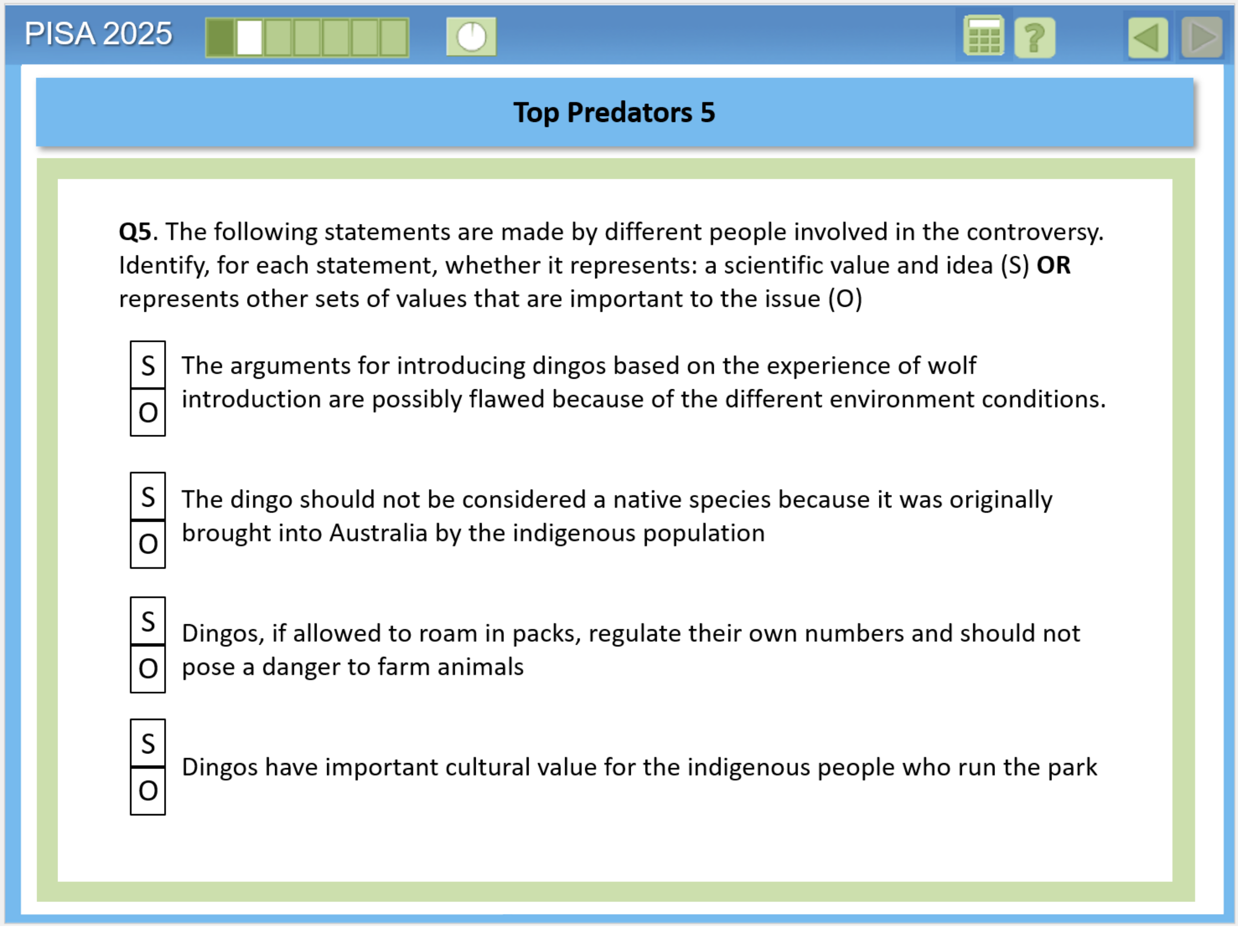


Table 25: Framework categorisation for TOP PREDATORS Question 5

Framework categories	2025 Framework
Knowledge type	Epistemic & Content
Competency	Research, Evaluate & Use Information for Decision Making and Action
Context	Environmental Impacts & Climate Change (Local)
Cognitive demand	High

TOP PREDATORS: Question 6

PISA 2025

Top Predators 6

Sources of Evidence

Consider the statements below from various sources

Q6. Identify those sources that you think can be trusted.

- ☐ Scientific studies of biodiversity in the area reported in peer-reviewed papers
- ☐ An article discussing the science, in a magazine of the Farmers Federation
- ☐ An article in 'tourism weekly' about the park and the issue
- ☐ A government report that summarises the relevant scientific reports in reputable journals
- ☐ A blog post that describes stories of dingos and their behaviour in different parts of the country
- ☐ A local newspaper report of evidence presented at the local council meeting
- ☐ A twitter post about the issue that describes the failure of top predator introductions around the world

Table 26: Framework categorisation for TOP PREDATORS Question 6

Framework categories	2025 Framework
Knowledge type	Epistemic
Competency	Research, Evaluate & Use Information for Decision Making and Action
Context	Environmental Impacts & Climate Change (Local)
Cognitive demand	Medium

Science Example 9: The Environmental Impact of Eating Meat

EATING MEAT: Question 1 & 2

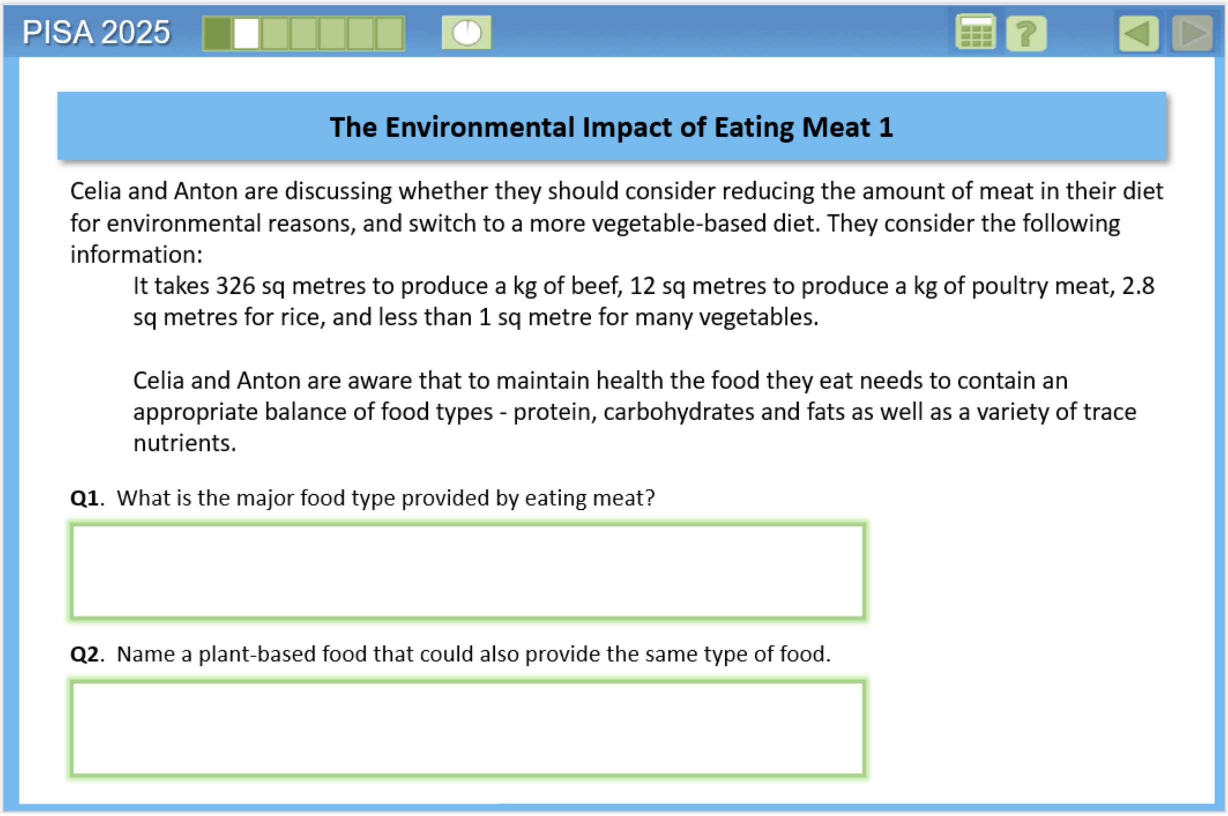


Table 27: Framework categorisation for EATING MEAT Question 1

Framework categories	2025 Framework
Knowledge type	Content
Competency	Explain Phenomena Scientifically
Context	Environmental Impacts & Climate Change (Global)
Cognitive demand	Low

Table 28: Framework categorisation for EATING MEAT Question 2

Framework categories	2025 Framework
Knowledge type	Content
Competency	Explain Phenomena Scientifically
Context	Environmental Impacts & Climate Change (Global)
Cognitive demand	Low

EATING MEAT: Question 3

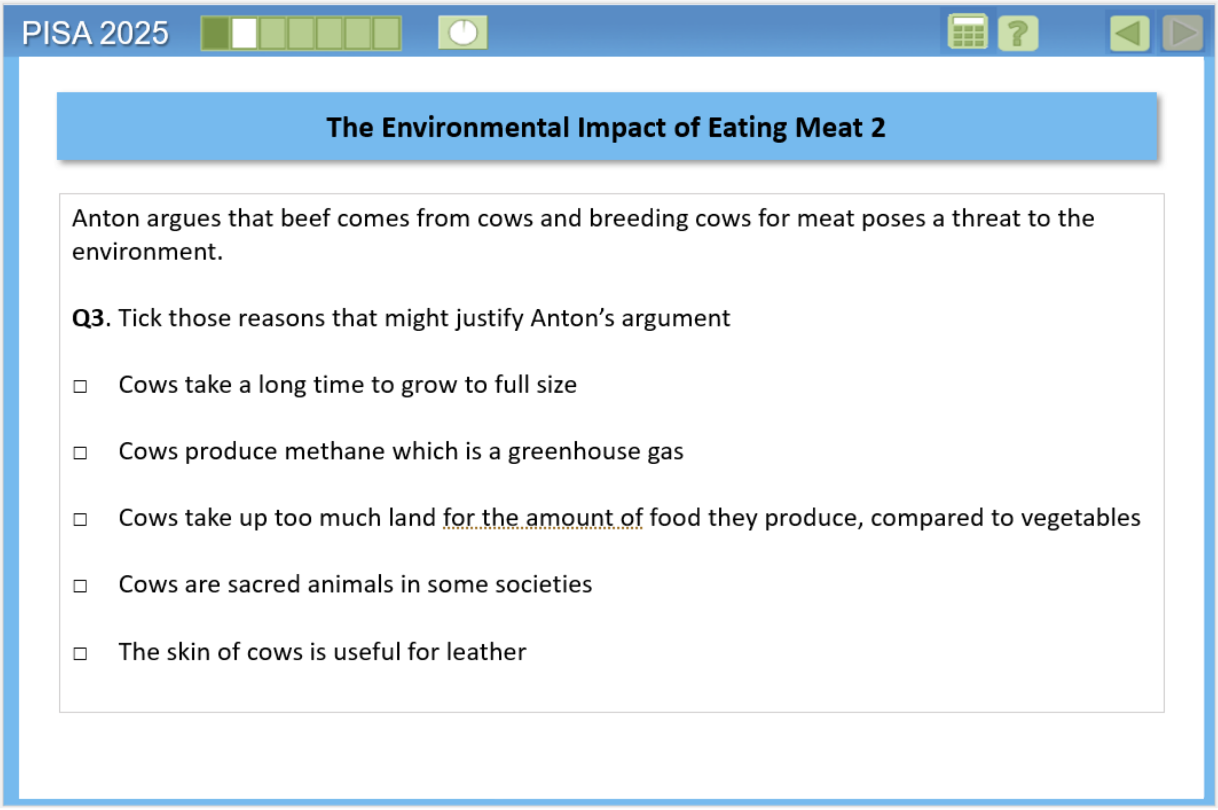


Table 29: Framework categorisation for EATING MEAT Question 3

Framework categories	2025 Framework
Knowledge type	Content, Epistemic & Socio-Ecological
Competency	Research, Evaluate & Use Information for Decision Making and Action
Context	Environmental Impacts & Climate Change (Global)
Cognitive demand	Medium

EATING MEAT: Question 4

PISA 2025

The Environmental Impact of Eating Meat 3

Celia says: ‘traditionally, humans have been omnivorous, consuming both meat and food such as grains, legumes, fruits. Meat, as part of a diet, delivers important food types and trace nutrients.

Anton replies: ‘an informed vegetarian diet can provide all these foods too! Since the world’s population is expanding, we need to reduce our forest clearance to provide pasture for cows and use our agricultural land more efficiently.’

Q4. Which of the following claims concerning ‘should we eat meat?’ can be justified using scientific evidence (S), and which is based on other types of knowledge or values (O)?

S	O	Our teeth are designed to eat meat
S	O	Some of our ceremonies involve eating meat and need to be maintained
S	O	A vegetarian human diet can provide all the food types and nutrients we need.
S	O	Meat tastes good we should not give it up
S	O	There is not enough available land to sustain current levels of meat production for a growing population.
S	O	Food production – especially meat production - is a major contributor to greenhouse gases, for instance through cows producing methane.
S	O	Meat is much more expensive than vegetables
S	O	Meat is a ready source of many of our nutritional needs
S	O	Meat production requires the extensive use of fertilizers. The overuse of fertilizers can pollute the land
S	O	To maximise efficiency of production hormones and drugs are sometimes used to make animals grow quickly and to keep them healthy in closely confined spaces. This drugs and hormones in this meat can negatively affect the health of people.

Table 30: Framework categorisation for EATING MEAT Question 4

Framework categories	2025 Framework
Knowledge type	Content & Epistemic
Competency	Research, Evaluate & Use Information for Decision Making and Action
Context	Environmental Impacts & Climate Change (Global)
Cognitive demand	High

8. The Evolution of the Science Assessment Framework in PISA

189. In PISA 2000 and 2003, the framework's primary focus was on scientific literacy which was defined as follows:

> *"Scientific literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity." (OECD, 2000, 2003)*

190. 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 resolving it into two components 'knowledge of science' and 'knowledge about science' (OECD, 2006). Both definitions, however, 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.

191. The PISA 2015 definition of scientific literacy was an evolution of these ideas. The major difference is that the notion of "knowledge about science" was specified more clearly and split into two components – procedural knowledge and epistemic knowledge.

192. 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 the gender difference on these issues (OECD, 2009; see also: Drechsel, Carstensen & Prenzel, 2011). More importantly, embedded items extended the length of the test. Hence for the 2015 framework attitudinal aspects were only measured through the student questionnaire and there were no embedded attitudinal items. As to the constructs measured within this domain, the first ('Interest in science') and third ('Environmental awareness') remained the same as in 2006. The second 'Support for scientific enquiry', however, was changed to a measure of 'Valuing scientific approaches to enquiry' – which was essentially a change in terminology to better reflect what was measured.

193. In PISA 2015, the contexts for assessment were changed from 'Personal, Social and Global' in the 2006 Assessment to 'Personal, Local/National and Global' to make the headings more coherent. This has been retained for the 2025 assessment.

194. In developing the framework for PISA 2025, four major changes have been made. First it was decided to merge the two previous competencies "Evaluate and design scientific enquiry" and "Interpret data and evidence scientifically" into one competency now called "Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically". The change of language was simply to place more emphasis on the evaluation of designs as few adults are likely to be engaged in designing experiments. This change was made as both competencies were felt to be part of the process of engaging in enquiry. In addition, the change in the societal context which, as outlined above, is now dominated by information sources on the Internet, many of them scientific, placed a new emphasis on educating students to "research, evaluate and use scientific information for decision making and action". Hence, the addition of this third new competency.

195. The second change was a shift from the specific focus on science literacy to a definition which, while encompassing this concept, is broader. Previously the framework has used the term ‘science literacy’ as the outcome of science education. The 2025 framework has chosen to phase out the term to avoid any confusion. This change bring it into line with the framework for mathematics and reading.

196. The third is to change the affective factors influencing the competency from a focus on attitudes towards science to a focus on measuring a broader concept of ‘science identity’ which has been shown to be more comprehensive in describing students' engagement in science.

197. The fourth is the focus on education for sustainability and the development of a scale to measure elements of Agency in the Anthropocene.

198. In addition, the body of defined content knowledge has been revised to make it more coherent with more emphasis on the major ideas of science while the definitions of procedural and epistemic knowledge have been extended and clarified.

199. In summary, the PISA 2025 definition builds on and develops the PISA 2006 and PISA 2015 definitions, broadening the competencies and clarifying the ideas and knowledge required.

9. Summary

200. Science will be the major domain in PISA 2025 and the 2025 definition builds on and develops the 2015 definition of scientific literacy. In particular, two of the competencies – "Evaluate and design scientific enquiry" and "Interpret data and evidence scientifically" – in the 2015 framework have been merged into one competency – "Construct and evaluate designs for scientific enquiry and interpret scientific data and evidence critically" with the addition of a third new competency "Research, evaluate and use scientific information for decision making and action". All of the competencies have been further elaborated as has the concepts of procedural and epistemic knowledge which were introduced in 2015. In addition, the 2025 framework has elaborated the conception of the cognitive demand required of items to provide greater guidance to item writers – specifically to produce more items at both ends of the spectrum of cognitive abilities. The 2025 framework therefore is an evolution of the conception of scientific literacy that is a response to the contemporary context where there is ever greater reliance on the evaluation and use of scientific information. In addition, it has built on and elaborated some of the earlier ideas found in previous frameworks. Given the multiple definitions of scientific literacy, this term has now been dropped and the framework is now referred to as the science framework.

201. The PISA 2025 definition of the outcomes of science education has its origin in the consideration of what 15-year-old students should know, value and be able to do as "preparedness for life" in modern society. Central to the definition and the assessment of the outcomes of science education are the competencies that are characteristic of science and scientific enquiry. The ability of students to make use of these competencies depends on their scientific knowledge, both their content knowledge of the natural world and their procedural and epistemic knowledge. In addition, it depends on a willingness to engage with science related topics. Their attitudes towards science-related issues are measured separately in the background questionnaire. In addition, the 2025 framework has elaborated a scale for students understanding of socio-ecological issues and the ways in which this might be measured.

202. This framework describes and illustrates the scientific competencies and knowledge that will be assessed in PISA 2025 (see Box 14), and the contexts for test items.

Box 14. Major components of the PISA 2025 framework for Science

Competencies	Knowledge	Science Identity

• Explain phenomena scientifically
• Construct and evaluate designs for scientific enquiry and interpret data and evidence critically
• Research, evaluate and use scientific information for decision making and action.
	• Knowledge of the content of science:
	  • Physical systems
	  • Living systems
	  • Earth and space systems
	• Procedural knowledge
	• Epistemic knowledge
		• A critical science disposition
		• Valuing scientific perspectives and approaches to enquiry
		• Environmental concern, awareness and agency
		• Elements of science identity

203. Test items will be grouped into units with each unit beginning with stimulus material that establishes the context for items. A combination of item types will be used. Computer-based delivery for 2015 offers the opportunity for several novel item formats, including animations and interactive simulations. This will improve the validity of the test and the ease of scoring.

204. The ratio of items assessing students' content knowledge of science to items assessing procedural and epistemic knowledge of science will be about 3:2. Approximately 40 percent of the items will test the competency to explain phenomena scientifically, 30 per cent the competency to construct and evaluate designs for scientific enquiry and interpret data and evidence critically, and 30 per cent their competency to research, evaluate and use scientific information for decision making. The cognitive demand of items will consist of a range of low, medium and hard. The combination of these weightings and a range of items of varying cognitive demand will enable proficiency levels to be constructed to describe performance in the three competencies that define the outcomes of scientific education.

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