



4

PISA 2012 Problem-Solving Framework

This chapter presents the framework underlying the PISA 2012 computer-based assessment of individual problem-solving competency, including the rationale for the assessment, the framework's research underpinnings and a definition of what is meant by problem-solving competency. The definition is discussed in detail, as are the three key domain elements of most importance for the assessment: the problem context, the nature of the problem situation, and the cognitive processes involved in solving a problem.

The general structure of the assessment and its computer delivery are described, including the test interface and the response formats employed. The distributions of items by problem nature and context, and according to cognitive process, are specified. The inclusion of problems that require the solver to interact with the problem situation to uncover necessary information not explicitly disclosed is highlighted. Sample items are presented with commentary, including an illustration of how response data (captured by the computer-delivery system) is used to enhance scoring.



INTRODUCTION

Problem-solving competency is a central objective within the educational programmes of many countries. The acquisition of increased levels of problem-solving competency provides a basis for future learning, for effective participation in society and for conducting personal activities. Citizens need to be able to apply what they have learnt to new situations. The study of individuals' problem-solving strengths provides a window into their capabilities to employ basic thinking and other general cognitive approaches to confronting challenges in life (Lesh and Zawojewski, 2007).

Background to the 2012 assessment

Problem solving was an additional assessment domain in PISA 2003. Some key findings of the survey were as follows (OECD, 2005):

- In some countries 70% of students could solve relatively complex problems, while in others less than 5% could do so.
- In most countries, more than 10% of students were unable to solve basic problems.
- On average in OECD countries, half of the students were unable to solve problems that are more difficult than basic problems.
- Patterns of within-country variation in students' problem-solving proficiency differed considerably across countries.
- Patterns of within-country differences between problem-solving proficiency and domain-related proficiencies (mathematics, reading and science) differed considerably across countries.

Since the 2003 problem solving assessment framework was developed (OECD, 2003a), considerable research has been carried out in the areas of complex problem solving, transfer, computer-based assessment of problem solving, and large-scale assessment of problem-solving competency (e.g. Blech and Funke, 2005; Funke and Frensch, 2007; Greiff and Funke, 2008; Klieme, 2004; Klieme et al., 2005; Leutner et al., 2004; Mayer, 2002; Mayer and Wittrock, 2006; O'Neil, 2002; Osman, 2010; Reeffer et al., 2006; Wirth and Klieme, 2004). This research has led to advances in understanding and measuring individuals' problem-solving capabilities.

In addition, advances in software development tools and the use of networked computers have made greater efficiency possible and have increased the effectiveness of assessment, including the capability to administer dynamic and interactive problems, engage students' interest more fully and capture more information about the course of the problem-solving process. On this last point, computer delivery of assessment tasks makes it possible to record data about such things as the type, frequency, length and sequence of actions performed by students when responding to items.

It is appropriate, therefore, to once again make problem solving an assessment domain in PISA, but in doing so to devise a new framework and implement additional assessment methodologies that allow for the real-time capture of students' capabilities. In particular, the PISA 2012 assessment of problem solving is computer-based and the student's interaction with the problem is a central feature of the assessment.

PISA 2012 problem solving is an assessment of individual problem-solving competency. Collaborative problem-solving skills – the skills required to solve problems as a member of a group – are essential for successful future employment, where the individual is often a member of a team of diverse specialists working in separate locations. However, the significant measurement challenges associated with including collaborative tasks in a large-scale international survey such as PISA (Reeffer et al., 2006), and the time needed to develop an appropriate computer-delivery platform, did not allow them to be a feature of the 2012 assessment.

A consistent research finding is that expert problem solving is dependent on domain-specific knowledge and strategies (e.g. Mayer, 1992; Funke and Frensch, 2007). The PISA 2012 assessment will avoid the need for expert knowledge as much as possible in order to focus on measuring the cognitive processes fundamental to problem solving. This also distinguishes the assessment from problem-solving tasks in the core PISA literacy domains of reading, mathematics and science, which call on expert knowledge in these areas.

Another conclusion that can be drawn from recent research is that authentic, relatively complex problems, particularly those that require direct interaction by the solver to uncover and discover relevant information, should be a central feature of the PISA 2012 problem-solving assessment. Examples are the problems commonly faced when using unfamiliar everyday devices such as remote controls, personal digital devices (e.g. mobile phones), home appliances and vending machines. Other examples arise in situations such as athletic training, animal husbandry, growing plants and social interactions. Problem-solving skills are necessary to achieve more than a basic level of skill when dealing with such situations and there is evidence that further skills, in addition to those involved in traditional reasoning-based problem



solving, are required (e.g. Klieme, 2004). This is the first time that such “interactive problems” have been included in a large-scale international survey, which has been made possible by computer delivery of the assessment.

Problem-solving competency can be developed by high-quality education. Progressive teaching methods, like problem-based learning, inquiry-based learning, and individual and group project work, can be used to foster deep understanding and prepare students to apply their knowledge in novel situations. Good teaching promotes self-regulated learning and metacognition and develops the cognitive processes that underpin problem solving. It prepares students to reason effectively in unfamiliar situations, and to fill gaps in their knowledge by observation, exploration and interaction with unknown systems. The PISA 2012 computer-based assessment of problem solving aims to examine how students are prepared to meet unknown future challenges for which teaching of today’s knowledge is not sufficient.

Problem solving in the OECD survey of adult skills

The OECD survey of adult skills is an assessment of reading component skills, literacy, numeracy and problem solving in technology-rich environments. It is a face-to-face sample household survey of people aged 16 - 65 years and was conducted for the first time in 2011, with results to be published in 2013.

The survey’s assessment of “problem solving in technology-rich environments” differs from the PISA 2012 assessment of problem solving in two important aspects.¹ First, it is primarily concerned with “information-rich” problems. Examples include needing to locate and evaluate information on the Internet or on social networking sites, navigating through unfamiliar web pages and making decisions about what information is relevant and irrelevant for a task.

A second major difference is that problem solutions require the use of one or more computer software applications (file management, web browser, email and spreadsheet). In PISA, information and communication technology (ICT) is integral to the assessment of problem solving but it is not integral to its definition of problem solving. Only foundational ICT skills (based on use of a keyboard and mouse) are necessary to take the PISA computer-based assessment of problem solving. Software tools are common and are powerful aids for information-rich problem solving; a high level of ICT literacy is essential in this digital age. However, the PISA assessment focuses on the fundamental cognitive processes that are essential for successful problem solving with or without ICT assistance.

DEFINING PROBLEM-SOLVING COMPETENCY

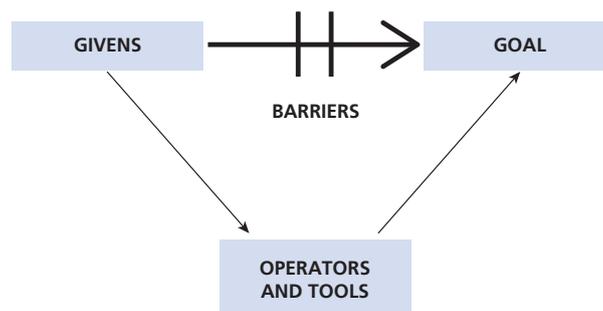
The aim of the PISA 2012 problem-solving assessment is to assess individual problem-solving *competency*. Before defining what is meant by the term “problem-solving competency” in this context, it is important to clarify what is meant by the terms “problem” and “problem solving” by researchers in the field.

Definition of a problem

A problem exists when a person has a goal but doesn’t know how to achieve it (Duncker, 1945). This definition is enlarged upon in Figure 4.1. The given state (givens) is the knowledge the person has about the problem at the outset and the operators are the admissible actions that can be performed to achieve the desired goal state (outcomes) with the assistance of the available tools. Barriers that must be overcome (e.g. lack of knowledge or obvious strategies) stand in the way of achieving the goal. Overcoming the barriers may involve not only cognition, but also motivational and affective factors (Funke, 2010).

■ Figure 4.1 ■

Problem situation



Source: Frensch and Funke, 1995.



As an example, consider the simple problem of finding the quickest route between two towns, when given a road map with estimated travel times marked and a calculator. The given state is the given information – the map with no route marked – and the goal state is the desired answer – the quickest route. The allowable actions (operators) are: selecting a possible route, calculating its total time and comparing it with the times for other routes. A tool (calculator) is available for assistance in adding times.

Definition of problem solving

Consistent with this understanding of what is meant by a problem, Mayer (1990) defines problem solving as cognitive processing directed at transforming a given situation into a goal situation when no obvious method of solution is available. This definition is widely accepted in the problem-solving community (e.g. see Klieme, 2004; Mayer and Wittrock, 2006; Reeve et al., 2006).

Definition of problem-solving competency

The PISA 2012 definition of problem-solving competency is grounded in these generally-accepted meanings of “problem” and “problem solving.” It is as follows:

Problem-solving competency is an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen.

Not surprisingly, the first sentence of the definition is almost identical to the first part of the definition used for the PISA 2003 assessment of problem solving.² However, whereas the 2003 definition had only a cognitive dimension, with its latter part highlighting the cross-curricular nature of the assessment, an affective component has been introduced in the 2012 definition in line with the definition of competency as recognised by the OECD (OECD, 2003a).

What distinguishes the 2012 assessment of problem solving from the 2003 assessment is not so much the definition of problem-solving competency, but the mode of delivery of the 2012 assessment (computer-based) and the inclusion of problems that cannot be solved without the solver interacting with the problem situation.

In the following paragraphs, each part of the PISA 2012 definition of problem-solving competency is considered in turn to help clarify its meaning in relation to the assessment.

Problem-solving competency...

A competency involves far more than the basic reproduction of accumulated knowledge. It involves a mobilisation of cognitive and practical skills, creative abilities and other psychosocial resources such as attitudes, motivation and values (OECD, 2003b). The PISA 2012 assessment of problem-solving competency will not test simple reproduction of domain-based knowledge; rather it will focus on the cognitive skills required to solve unfamiliar problems that are encountered in life³ and that lie outside traditional curricular domains.

Prior knowledge is important in solving problems. However, problem-solving competency involves the ability to acquire and use new knowledge, or to use old knowledge in a new way to solve novel problems (i.e. problems that are not routine).

...is an individual's capacity to engage in cognitive processing...

Problem solving occurs internally in an individual's cognitive system and can only be inferred indirectly by the person's actions and products. It involves representing and manipulating various types of knowledge in the problem solver's cognitive system (Mayer and Wittrock, 2006). Students' responses to assessment items – their exploration strategies, the representations they employ in modelling the problem, numerical and non-numerical answers, or extended explanations of how a problem was solved – will be used to make inferences about the cognitive processes they employed.

Creative (divergent) thinking and critical thinking are important components of problem-solving competency (Mayer, 1992). Creative thinking is a cognitive activity that results in finding solutions to a novel problem. Critical thinking accompanies creative thinking and is employed to evaluate possible solutions. The PISA 2012 assessment will target both components.

...to understand and resolve problem situations...

To what degree can individuals meet the challenges of a problem situation and move towards resolving it? In addition to explicit responses to items, the assessment aims to measure individuals' progress in solving a problem, including



the strategies they employ. Where appropriate these strategies are tracked by means of behavioural data captured by the computer-delivery system: the type, frequency, length and sequence of interactions made with the system can be captured and used in scoring or in subsequent analyses of student performance.

Problem solving begins with recognising that a problem situation exists and establishing an understanding of the nature of the situation. It requires the solver to identify the specific problem(s) to be solved and to plan and carry out a solution, along with monitoring and evaluating progress throughout the activity.

Often in real-world problems there may not be a unique or exact solution. In addition, the problem situation may change during the solving process, possibly due to interaction with the problem solver or as a result of its own dynamic nature. These complexities were addressed when setting assessment tasks with the aim of striking a balance between the authenticity of a situation and the practicality of the assessment.

...where a method of solution is not immediately obvious...

The means of finding a solution path should not be immediately obvious to the problem solver. There will be barriers of various sorts in the way, or missing information. The assessment is concerned with non-routine problems and not routine ones (i.e. problems for which a previously learnt solution procedure is clearly applicable): the problem solver must actively explore and understand the problem and either devise a new strategy or apply a strategy learnt in a different context to work towards a solution.

The status of a problem – whether it is routine or not – depends on the solver’s familiarity with the problem. A “problem” for one person may have an obvious solution to another person who is experienced and practised in solving such problems. Accordingly, care was taken to set problems that should be non-routine for the great majority of 15-year-olds.

It is not necessarily the case that the context or goals will themselves be unfamiliar to the solver; what is important is that the particular problems are novel or the ways of achieving the goals are not immediately obvious. The problem solver might need to explore or interact with the problem situation before attempting to solve the problem. Direct interaction is made feasible by the use of computer-delivered assessment in PISA 2012.

...It includes the willingness to engage with such situations...

Problem solving is personal and directed, that is, the problem solver’s processing is guided by their personal goals (Mayer and Wittrock, 2006). The problem solver’s individual knowledge and skills help determine the difficulty or ease with which obstacles to solutions can be overcome. However, the operation of such knowledge and skill is affected by motivational and affective factors such as beliefs (e.g. self-confidence) and feelings about one’s interest and ability to solve the problem (Mayer, 1998).

In addition, the context of a problem (whether it is familiar and understood), the external resources available to the solver (such as access to tools), and the environment in which the solver operates (e.g. an examination setting) will affect the way a person approaches and engages with the problem.

Motivational and affective factors will not be measured in the problem-solving cognitive assessment but the student questionnaire will contain groups of items measuring perseverance and openness with respect to problem solving generally. In addition, the questionnaire will include some questions that gather information on students’ problem-solving strategies (e.g. ask someone convenient, consult instructions, engage in unfocussed behaviour, give up) when confronted with specific problem situations.

...in order to achieve one’s potential as a constructive and reflective citizen.

Competency is an important factor in the ways that individuals help to shape the world, not just cope with it: “...key competencies can benefit both individuals and societies” (Rychen and Salganik, 2003). Individuals should “manage their lives in meaningful and responsible ways by exercising control over their living and working conditions” (*ibid*). They need to be proficient problem solvers to achieve their potential as constructive, concerned and reflective citizens.

Scope of the assessment

The PISA 2012 problem-solving assessment will not include problems that require expert knowledge for their solution. In particular, problems that could reasonably be included in an assessment of one of the three PISA core domains will not be included. Assessment tasks will centre on everyday situations, with a wide range of contexts employed as a means of controlling for prior knowledge in general.



Mobilisation of prior knowledge is not sufficient to solve novel problems in many everyday situations. Instead of a straightforward application of previously mastered knowledge, existing knowledge needs to be re-organised and combined with new knowledge using a range of reasoning skills. Gaps in knowledge must be filled through observation and exploration of the problem situation. This often involves interaction with a new system to discover rules that in turn must be applied to solve the problem. Such problems are the major focus of the PISA 2012 problem-solving assessment, made possible by it being computer based.

ORGANISING THE DOMAIN

How the domain is represented and organised determines the assessment design and, ultimately, the evidence about student proficiencies that can be collected and reported. Many elements are part of the construct, not all of which can be taken into account and varied in an assessment such as PISA. The most important elements must be identified so that they can be varied to ensure construction of an assessment that contains items which have an appropriate range of difficulty and provide a broad coverage of the domain.

The domain elements of key importance for the PISA 2012 problem-solving assessment are as follows:

- The problem context: whether it involves a technological device or not, and whether the focus of the problem is *personal* or *social*.
- The nature of the problem situation: whether it is *interactive* or *static*.
- The problem-solving processes: the cognitive processes involved in solving a problem.

Items were developed to measure how well students perform when the various problem-solving processes are exercised within the two different types of problem situations across a range of contexts. Each of these key domain elements is discussed and illustrated in the following sections.

Problem context

An individual's familiarity and understanding of the problem context will affect how difficult the problem is to solve for that person. Two dimensions have been identified to ensure that assessment tasks sample across a range of contexts that are authentic and of interest to 15-year-olds: the setting (technology or not) and the focus (personal or social).

Problems set in a *technology* context have the functionality of a technological device as their basis. Examples include mobile phones, remote controls for appliances and ticket vending machines. Knowledge of the inner workings of these devices will not be required: typically, students are led to explore and understand the functionality of a device, as preparation for controlling the device or for troubleshooting its malfunctioning. Situations that give rise to other types of problems, such as route planning, task scheduling and decision making, have *non-technology* contexts.

Personal contexts include those relating primarily to the self, family and peer groups. *Social* contexts relate to situations typically encountered more broadly in the community or society in general (including at work and in undertaking further education). As illustrations, the context of an item about setting the time on a digital watch would be classified as *technology* and *personal*, whereas the context of an item requiring the construction of a basketball team roster would be classified as *non-technology* and *social*. The last section of this chapter gives further examples: the first sample unit described, which focuses on the rules that govern the functioning of an MP3 player, has a *technology* and *personal* context, and the second, about the seating plan for a birthday party, has a *non-technology* and *social* context.

Nature of the problem situation

How a problem is presented has important consequences for how it can be solved. Of crucial importance is whether the information about the problem disclosed to the problem solver at the outset is complete. This is the case for the quickest-route problem discussed earlier (see the section "Definition of a problem"). We refer to such problem situations as being *static*. The unit *BIRTHDAY PARTY*, described in the section "Illustrative PISA problem solving items" is an example of a *static* unit.

By contrast, problem situations may be *interactive*, meaning that exploration of the situation to uncover additional relevant information is possible.⁴ Real-time navigation using a GPS system where traffic congestion is reported automatically or by query, presents such a situation. The unit *MP3 PLAYER*, described in the section "Illustrative PISA problem solving items" is *interactive*.

Interactive problem situations can be simulated in a test setting by means of a computer. Including interactive problem situations in the computer-based PISA 2012 problem-solving assessment allows a wide range of more authentic,



real-life scenarios to be presented than would otherwise be possible using pen-and-paper tests. Problems where the student explores and controls a simulated environment are a distinctive feature of the assessment.

A selection of static problem situations also is included in the assessment. The assessment of such problems has traditionally taken place using pen-and-paper tests. However, their computer-based assessment has many advantages including the capability of presenting a broader range of scenarios, involving multimedia elements such as animation; the availability of online tools; and, the use of a wide range of response formats that can be automatically coded.

Furthermore, some studies suggest that knowledge acquisition in exploring a problem in an interactive environment, and how that knowledge is applied, are competencies distinct from the typical skills used in solving static problems (see Klieme, 2004; Wirth and Klieme, 2004; Leutner and Wirth, 2005). Including a mixture of interactive and static problems in the PISA 2012 assessment therefore will provide a broader measure of problem-solving competency than has been possible with pen-and-paper instruments.

Interactive problem situations

Interactive problem situations often arise when encountering technological devices such as ticket vending machines, air-conditioning systems or mobile telephones for the first time, especially if the instructions for using them are not clear or are not available. Understanding how to control such devices is a problem faced universally in everyday life. In these situations it is often the case that some relevant information is not apparent at the outset. For example, the effect of applying an operation (say, pushing a button on a remote control) may not be known and cannot be deduced, but rather must be inferred by interacting with the scenario through actually performing the operation (pushing the button) and forming a hypothesis about its function based on the outcome. In general, some exploration or experimentation must be done to acquire the knowledge necessary to control the device. Another common scenario is when a person must troubleshoot a fault or malfunction in a device. Here a certain amount of experimentation must take place to collect data on the circumstances under which the device fails.

An interactive problem situation can be dynamic, meaning that its state might change of its own accord due to influences beyond the problem solver's control (i.e. without any intervention by the problem solver).⁵ For example, in the case of a ticket-vending machine, if during a transaction no buttons are pressed for 20 seconds, the machine might reset. Such autonomous behaviour of a system must be observed and understood so it can be taken into account in attaining the desired goal (purchasing a ticket).

Static problem situations

Static problem situations can give rise to well-defined or ill-defined problems. In a well-defined problem, such as the quickest-route problem (see the section "Definition of a problem"), the given state, goal state and allowable operators are clearly specified (Mayer and Wittrock, 2006). The problem situation is not dynamic (i.e. does not change of its own accord during the course of solving the problem), all relevant information is disclosed at the outset and there is a single goal.

Other examples of well-defined problems are traditional logic puzzles such as the Tower of Hanoi and the water jars problems (see, for example, Robertson, 2001); decision-making problems, where the solver is required to understand a situation involving a number of well-defined alternatives and constraints so as to make a decision that satisfies the constraints (e.g. choosing the right pain killer given sufficient details about the patient, the complaint and the available pain killers); and, scheduling problems for projects such as building a house or producing computer software, where a list of tasks with durations and dependencies between tasks is given.

Mayer and Wittrock (2006) point out that "educational materials often emphasise well-defined problems, although most real problems are ill-defined [i.e. not well-defined]". These latter problems, which may be interactive or static in nature, often involve multiple goals which are in conflict so that progress towards one may detract from progress towards the other(s). Elaboration and weighing of priorities is required for the problem solver to achieve a balance between the goals (Blech and Funke, 2010). An example is finding the "best" route between two places – should this be the shortest route?, the likely quickest route?, the most straightforward route?, the route with minimum variation in time?, etc. A more complex example is designing a car where high efficiency, low cost, high safety and low environmental footprint may all be desired.

Problem-solving processes

Different authors conceive of the cognitive processes involved in solving a problem in different ways, but there is a great deal of commonality in their views. The processes identified are derived from the work on problem solving and reasoning of cognitive psychologists (e.g. Baxter and Glaser, 1997; Bransford et al., 1999; Mayer and Wittrock, 1996, 2006; Vosniadou



and Ortony, 1989), as well as by the seminal work of Polya (1945). Additionally, recent work on complex and dynamic problem solving (Blech and Funke, 2005, 2010; Funke and Frensch, 2007; Greiff and Funke, 2008; Klieme, 2004; Osman, 2010; Reef et al., 2006; Wirth and Klieme, 2004) has been taken into account.

No assumption is made that the processes involved in solving a particular problem are sequential or that all of the processes listed are involved in solving a particular problem. As individuals confront, structure, represent and solve authentic problems representing emerging life demands, they may move to a solution in a way that transcends the boundaries of a linear, step-by-step model. Most of the information about the functioning of the human cognitive system now supports the view that it is capable of parallel information processing (Lesh and Zawojewski, 2007).

For the purposes of the PISA 2012 problem-solving assessment, the processes involved in problem solving are taken to be:

- *Exploring and understanding*
- *Representing and formulating*
- *Planning and executing*
- *Monitoring and reflecting*

Exploring and understanding. The objective here is to build mental representations of each of the pieces of information presented in the problem. This involves:

- exploring the problem situation: observing it, interacting with it, searching for information and finding limitations or obstacles; and
- understanding given information and information discovered while interacting with the problem situation; demonstrating understanding of relevant concepts.

Representing and formulating. The objective here is to build a coherent mental representation of the problem situation (i.e. a situation model or a problem model). To do this, relevant information must be selected, mentally organised and integrated with relevant prior knowledge. This may involve:

- representing the problem by constructing tabular, graphical, symbolic or verbal representations, and shifting between representational formats; and
- formulating hypotheses by identifying the relevant factors in the problem and their interrelationships; organising and critically evaluating information.

Planning and executing includes:

- planning, which consists of goal setting, including clarifying the overall goal, and setting sub-goals, where necessary; and devising a plan or strategy to reach the goal state, including the steps to be undertaken; and
- executing, which consists of carrying out a plan.

Monitoring and reflecting includes:

- monitoring progress towards the goal at each stage, including checking intermediate and final results, detecting unexpected events, and taking remedial action when required; and
- reflecting on solutions from different perspectives, critically evaluating assumptions and alternative solutions, identifying the need for additional information or clarification and communicating progress in a suitable manner.

Reasoning skills

Each of the problem-solving processes draws upon one or more reasoning skills. In understanding a problem situation, the problem solver may need to distinguish between facts and opinion; in formulating a solution, the problem solver may need to identify relationships between variables; in selecting a strategy, the problem solver may need to consider cause and effect; and, in communicating the results, the problem solver may need to organise information in a logical manner. The reasoning skills associated with these processes are embedded within problem solving. They are important in the PISA context since they can be taught and modelled in classroom instruction (e.g. Adey et al., 2007; Klauer and Phe, 2008).

Examples of reasoning skills employed in problem solving include deductive, inductive, quantitative, correlational, analogical, combinatorial and multidimensional reasoning. These reasoning skills are not mutually exclusive and often in practice problem-solvers move from one to another in gathering evidence and testing potential solution paths before



settling into the major use of one method over others in finding the solution to a given problem. Reasoning skills have been broadly sampled across the assessment items because the difficulty of an item is influenced by the complexity and types of reasoning involved in its solution.

ASSESSING PROBLEM-SOLVING COMPETENCY

Structure of the assessment

The duration of the PISA 2012 computer-delivered assessment is 40 minutes. A total of 80 minutes of problem-solving material is organised into four 20-minute clusters. Students from countries not participating in the optional computer-based assessment of mathematics and digital reading will do two of the clusters according to a balanced rotation design. Students from countries also participating in the optional computer-based assessment of mathematics and digital reading will do two, one or none of the four problem-solving clusters according to a separate balanced rotation design.

As is normal for PISA assessments, items are grouped into units based around a common stimulus that describes the problem situation. To minimise the level of reading literacy required, stimulus material (and task statements) are as clear, simple and brief as possible. Animations, pictures or diagrams have been used to avoid lengthy passages of text. Numeracy demands have also been kept to a minimum with, for example, running totals provided where appropriate.

There are 16 units altogether, comprising a total of about 40 items that have an appropriate range of difficulty. This will enable the strengths and weaknesses of populations and key subgroups to be determined with respect to the cognitive processes involved in problem solving.

Functionality provided by computer delivery

A principal benefit of measuring problem-solving competency through a computer-based assessment is the opportunity to collect and analyse data that relate to processes and strategies, in addition to capturing and scoring intermediate and final results. This is likely to be a major contribution of the PISA 2012 assessment of problem solving. With appropriate item authoring, data such as the type, frequency, length and sequence of actions performed by students can be captured for this purpose.

Only foundational ICT skills are assumed in the assessment, such as keyboard use, using a mouse or touchpad, clicking radio buttons, drag-and-drop, scrolling, and use of pull-down menus and hyperlinks. Care will be taken to ensure that interference with the measurement of problem-solving competency by ICT demand and presentation is kept to a minimum.

Both units and items within units will be delivered in a fixed order, or “lockstep” fashion. The lockstep procedure means that students are not able to return to an item or unit once they have moved to the next one. Each time students click the *Next* button a dialog box will display a warning that they are about to move on to the next item and that it will not be possible to return to the previous item. At this point, students can either confirm they want to move on or cancel the action and return to the current item.

The appearance of the test interface is consistent across items (see Figure 4.2). For each item the stimulus material appears in the top part of the screen. The item question appears in the lower part of the screen, and is separated visually from the stimulus through the use of borders. The division of the screen into two parts varies from item to item so that scrolling is never required to see all information.

At the top right of the screen a timing bar appears which shows how much time is remaining in the assessment. Down the left edge of the screen another indicator of progress is given: the items in the test are listed in unit groups, with the current item number highlighted.

Task characteristics and difficulty

Generally, each item will focus on a single problem-solving process as far as possible. Accordingly, for some items, demonstrating a recognition of the problem will be sufficient; in others, describing a method of solution will be enough; in many, the actual solution(s) will be required with effectiveness and efficiency of method being important characteristics; in yet others, the task will be to evaluate proposed solutions and decide on the most appropriate solution for the problem posed. Including items that focus on one process is appropriate because although executing is often emphasised in classroom instruction, the major difficulties for most problem solvers involve representing, planning and self-regulating (Mayer, 2003).

Some problems are inherently more complex than others (Funke and Frensch, 2007). Furthermore, increased complexity generally means greater difficulty. Table 4.1 summarises task characteristics that are varied in the assessment to ensure that the items cover an appropriate range of difficulty. These characteristics are not mutually exclusive and can be regarded as forming four factors (Philpot et al., 2012) when the PISA 2012 problem set is analysed.

■ Figure 4.2 ■

The test interface

en-GB Programme for International Student Assessment 2012

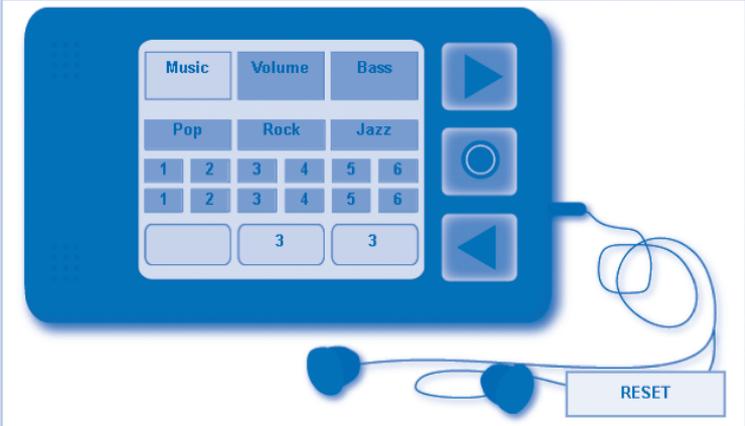
1
2
3

MP3 PLAYER

A friend gives you an MP3 player that you can use for playing and storing music. You can change the type of music, and increase or decrease the volume and the bass level by clicking the three buttons on the player.

(▶, ●, ◀)

Click RESET to return the player to its original state.



Question 1: MP3 PLAYER CP043Q03

The bottom row of the MP3 player shows the settings that you have chosen. Decide whether each of the following statements about the MP3 player is true or false. Select "True" or "False" for each statement to show your answer.

Statement	True	False
You need to use the middle button (●) to change the type of music.	<input type="radio"/>	<input type="radio"/>
You have to set the volume before you can set the bass level.	<input type="radio"/>	<input type="radio"/>
Once you have increased the volume, you can only decrease it if you change the type of music you are listening to.	<input type="radio"/>	<input type="radio"/>

?

➔

Response formats and coding

About one-third of the items require students to select their response(s) by clicking a radio button or by selecting from a drop-down menu. This includes simple multiple-choice items where there is one correct response to be selected, complex multiple-choice items where two or three separate multiple-choice selections must be made, and variations of these such as when there is more than one correct response to be selected from a list or multiple drop-down menus. All of these items are automatically coded.

Just over half the items require students to construct their responses but in a manner that can be automatically coded, such as by entering a number, dragging shapes, drawing lines between points or highlighting part of a diagram.

The remaining items require students to enter their responses in text boxes and need to be coded by experts. Such items are used in particular where it is considered important to ask students to explain their method or justify a selected response.

An online coding system has been developed to facilitate coding by experts. This eliminates the need for separate data entry, minimises the need for data cleaning, and allows coding to take place "off site" if desired.

The coding scheme for an item will allow for partial credit if appropriate, such as when multiple correct answers are required for full credit or when a correct strategy is employed but is not executed properly. Designated behaviours (such as exploration strategies) that provide reliable evidence about problem-solving competency over and above the fulfilment of task demands will be captured and will contribute to scoring.



Table 4.1
Task characteristics

Characteristic	Effect on task difficulty
Amount of information	The more information that has to be considered, the more difficult the task is likely to be.
Representation of information	Unfamiliar representations, and multiple representations (especially when information presented in different representations has to be related), tend to increase difficulty.
Degree of abstraction	How abstract or concrete the scenario is will affect the level of difficulty of a task. It is likely that the more abstract a scenario, the more difficult the task.
Familiarity of context	If a context is familiar to a problem solver, the solver may feel better equipped to tackle the problem.
Disclosure of information	The more that relevant information has to be discovered (e.g. effect of operations, autonomous behaviour, unanticipated obstacles), the more difficult the task is likely to be.
Internal complexity	The internal complexity of a task increases as the number of components or elements increases and they become more interrelated (due to dependencies or constraints). Tasks with a high level of internal complexity are likely to be harder than those with lower levels of complexity.
Distance to goal	The greater the number of steps needed to solve a problem, the more difficult it is likely to be.
Reasoning skills required	The difficulty of a task is influenced by the complexity and types of reasoning skills involved in its solution. Tasks that require the application of some types of reasoning (e.g. combinatorial reasoning) are likely to be harder than those that do not.

Interactive problems

Interactive problems can be built on underlying formal models whose parameters can be varied systematically to achieve differing degrees of difficulty. There are two well-used paradigms: linear difference equations and finite state machines.

With problem situations modelled by linear difference equations (also referred to as linear structural equations),⁶ the problem solver must manipulate one or more input variables (such as controls for a climate control system) and consider the effect this has on one or more output variables (such as temperature and humidity); the output variables may also influence themselves so that the system is dynamic. Example contexts include remote controls, thermostats, paint mixing and ecosystems.

A finite state machine is a system with a finite number of states, input signals and output signals (Buchner and Funke, 1993).⁷ The system's next state (and output signal) is uniquely determined by its current state and the specific input signal. With problem situations modelled by finite state machines, the problem solver must supply input signals (usually in the form of a sequence of button presses) to determine the effect on the system's states in an effort to understand its underlying structure and move it towards a goal state. Many everyday devices and contexts are governed or constrained by the rules of a finite state machine structure. Examples include digital watches, mobile phones, microwave ovens, MP3-players, ticket vending machines and washing machines.

The typical task demands for such interactive problems are as follows (see Blech and Funke (2005) and Greiff and Funke (2008) for additional details):

- Exploration: acquire knowledge of system structure either by active or directed exploration (interaction). *[Exploration strategies can be tracked and captured by the computer delivery system.]*
- Identification: give or complete a representation of the mental model of the system that is formed during exploration. This may be in drawing or text form. *[The accuracy of the model helps in assessing acquired causal knowledge.]*
- Control: practical application of acquired knowledge: transform a given state into a goal state and (for appropriate systems) maintain the goal state over time. A correct model of the system may be provided to minimise dependence on previous items. *[Transfer of acquired knowledge is assessed in this way.]*
- Explanation: describe strategies used to reach a goal; explain how a system works; or suggest causes of a malfunction of a device.

Students may already have some idea of the relationships between system variables in problem situations because of their familiarity with similar, actual devices. Such prior knowledge will vary between individuals and so a variety of common, everyday problem contexts will be used to help overcome this effect across the assessment. In addition, a



few more unusual but engaging game-like contexts will be included where the relationships must be inferred solely by manipulation and observation of system variables.

The difficulty of problems of these types is largely dependent on the internal complexity of the formal models underlying the situations. Problems of varying difficulty can be set by systematically varying this complexity, which is determined by the number of variables involved and how they are connected. For example, a problem involving only a few variables can be very easy if it only involves direct effects between input and output variables, but can be made extremely difficult by the inclusion of multiple effects and side effects between output variables.

Distribution of items

For the main survey, the percentage distribution of score points according to the cognitive processes involved in problem solving is given in Table 4.2. The ranges recommended by the Problem Solving Expert Group are included in parentheses. Highest weighting is given to *planning and executing* in recognition of the importance of being able to carry through a solution to a successful conclusion. Lower than average weight is given to *monitoring and reflecting* because it is an integral part of the other three processes and therefore also is assessed (indirectly) in items that target those processes.

Table 4.2
Approximate distribution of score points in problem solving, by process

Exploring and understanding	Representing and formulating	Planning and executing	Monitoring and reflecting	Total
21.4% (20 - 25%)	23.2% (20 - 25%)	41.1% (35 - 45%)	14.3% (10 - 20%)	100%

Table 4.3 indicates the percentage distribution of items across the two other key domain elements, problem context and nature of the problem situation. Once again, the recommended ranges are given in parentheses. The clear emphasis on interactive problems over static problems (a ratio of about 2:1) reflects the decision to concentrate on this important class of problems that, with the advantage of computer delivery, it is possible to include in a large-scale international survey for the first time. The greater emphasis on technology contexts over non-technology contexts recognises both the ever-increasing role played by technological devices in everyday life and their suitability for simulation in a computer-delivered test.

Table 4.3
Approximate distribution of items in problem solving, by problem nature and context*

	Technology context	Non-technology context	Total contexts
Static problem situation	11% (10 - 15%)	20% (15 - 20%)	31% (25 - 35%)
Interactive problem situation	45% (40 - 45%)	25% (25 - 30%)	70% (65 - 75%)
Total problem natures	55% (50 - 60%)	45% (40 - 50%)	100%

*Discrepancies in totals are due to rounding errors.

A roughly equal balance between personal and social contexts was recommended, subject to the constraints imposed in satisfying the recommended distributions for the key domain elements as expressed in Tables 4.2 and 4.3. The actual division of score points in the main survey is 59% personal and 41% social.

REPORTING PROBLEM-SOLVING COMPETENCY

Consistent with the other PISA domains, the results of the problem solving assessment will be summarised on a single, composite problem-solving scale with a mean of 500 and a standard deviation of 100.

Easier tasks appear at the lower end of the scale, and harder tasks appear at the upper end of the scale. In an attempt to capture and summarise the progression of task difficulty, the scale will be divided into levels.



Six levels of proficiency will be described to show how individuals' problem solving competency grows and develops, and to enable comparisons of student performance between and within participating countries and economies. There are not enough items in the survey to report on subscales.

Proficiency descriptions characterising typical student performance at each level will be developed by analysing the knowledge and skills required to answer the tasks at that level, and the characteristics of those tasks (see Table 4.1). It is expected that the following abilities will characterise high-performing students:

- Ability to plan and execute solutions that involve thinking a number of steps ahead and meeting multiple constraints, to apply complex reasoning skills and to monitor progress towards a goal throughout the solution process, modifying plans where necessary.
- Ability to understand and make links across disparate pieces of information even when they are presented using unfamiliar representations.
- Ability to interact with problems systematically and intentionally to discover undisclosed information.

Students who have not yet reached a baseline level of proficiency are expected to have at most, the following characteristics:

- Ability to plan and execute solutions that involve a small number of steps.
- Ability to solve problems involving one or two variables and no constraints, or only a single constraint.
- Ability to formulate simple rules, and discover undisclosed information when exploring in an unsystematic manner.

SUMMARY

The PISA 2012 assessment of problem solving is the second time that individual problem-solving competency has been assessed in PISA. In 2003, a pen-and-paper test of cross-disciplinary problem solving was part of the assessment. By contrast, the PISA 2012 assessment is computer-delivered, which enables the inclusion of items that require the solver to interact with the problem situation. Furthermore, problems that require disciplinary knowledge for their solution are avoided so as to focus on measuring the cognitive processes fundamental to problem solving.

For the purposes of PISA 2012, problem-solving competency is defined as an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen.

The domain elements of key importance in developing assessment items are the problem context: *technological* or not, *personal* or *social*; the nature of the problem situation: interactive or static; and, the problem solving processes – the cognitive processes involved in problem solving: exploring and understanding, representing and formulating, planning and executing, monitoring and reflecting.

The nature of the problem situation is determined by whether the information disclosed to the solver at the outset about the problem situation is complete (static problems), or whether interaction with the problem situation is a necessary part of the solving activity in order to uncover additional information (interactive problems). Examples of interactive problems include problems commonly faced when using unfamiliar devices such as a new mobile phone or a ticket vending machine. This is the first time, made possible by computer delivery of the assessment, that such interactive problems have been included in a large-scale international survey.

Each test item, with its associated stimulus material, occupies a single computer screen and students proceed from item to item in a "lockstep" fashion. A variety of response formats are employed including selected-response and constructed-response that can be automatically coded (e.g. drag-and-drop), and free text entry that requires coding by experts. For some items, behavioural data that provides reliable evidence about problem-solving competency (e.g. exploration strategies) are captured and contribute to the scoring. Sample items are presented with commentary in the following section.

ILLUSTRATIVE PISA PROBLEM-SOLVING ITEMS

Items from two units that were included in the PISA 2012 field trial are described in this section.⁸ For each unit a screenshot of the stimulus information is provided, together with a brief description of the context of the unit. This is followed by a screenshot and description of each item from that unit.



MP3 PLAYER

■ Figure 4.3 ■

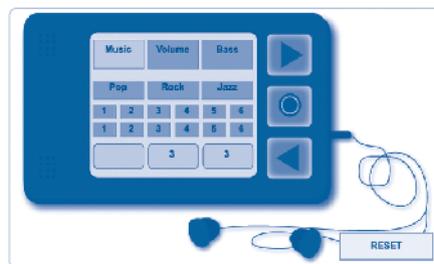
MP3 player: Stimulus information

MP3 PLAYER

A friend gives you an MP3 player that you can use for playing and storing music. You can change the type of music, and increase or decrease the volume and the bass level by clicking the three buttons on the player.

(▶, ●, ◀)

Click RESET to return the player to its original state.



In the unit MP3 Player, students are told that they have been given an MP3 Player by a friend. They do not know how it works and must interact it with it to find out, so the nature of the problem situation for each item in this unit is interactive. Since the focus of the unit is on discovering the rules that govern a device intended for use by an individual, the *context* of each item in the unit is *technology* and *personal*.

■ Figure 4.4 ■

MP3 player: Item 1

QUESTION 1

The bottom row of the MP3 player shows the settings that you have chosen.

Decide whether each of the following statements about the MP3 player is true or false. Select “True” or “False” for each statement to show your answer.

Statement	True	False
You need to use the middle button (●) to change the type of music.	<input type="radio"/>	<input type="radio"/>
You have to set the volume before you can set the bass level.	<input type="radio"/>	<input type="radio"/>
Once you have increased the volume, you can only decrease it if you change the type of music you are listening to.	<input type="radio"/>	<input type="radio"/>

In the first item in the unit, students are given a series of statements about how the system works and asked to identify whether they are true or false. The statements offer scaffolding for students to explore the system. The problem-solving *process* for this item is *exploring and understanding*, and the exploration is guided but unrestricted. A “Reset” button is available which allows students at any time to return to the player to its initial state, and re-commence their exploration if desired. There is no restriction on the number of times this can be done. In the field trial this was a somewhat harder than average item, with 38% of students gaining full credit (True, False, False), due probably to the requirement that all three answers must be correct and the degree to which information has to be uncovered (no information is known about the system at the outset and so all knowledge of the rules of the system must come from interacting with it). Partial credit was not available for this item.

■ Figure 4.5 ■

MP3 player: Item 2

QUESTION 2

Set the MP3 player to Rock, Volume 4, Bass 2.

Do this using as few clicks as possible. There is no RESET button.

The second item in the unit is classified as *planning and executing*. In this item students must plan how to achieve, and then execute, a given goal. Of interest for this partial credit item is that process information captured by the computer-delivery system (in this case, how many steps the student takes to successfully reach the goal state) contributes to the score. The task is to be completed using as few clicks as possible and the option of returning the machine to its initial



state by pressing the “Reset” button is not available. If the number of clicks used (no more than 13) indicates that students have been efficient in reaching the goal they receive full credit, but if they reach the goal in a less efficient manner they only receive partial credit. The requirement for efficiency contributed to making it somewhat harder than average to obtain full credit for this item, though it was fairly easy to obtain partial credit. In the field trial, about 39% of students received full credit and about 33% received partial credit.

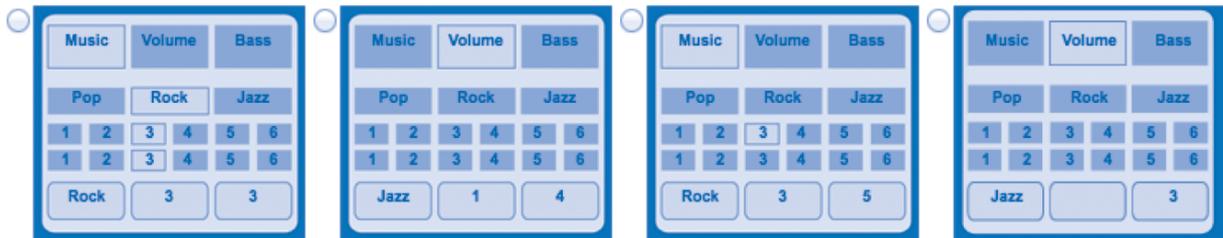
■ Figure 4.6 ■

MP3 player: Item 3

QUESTION 3

Shown below are four pictures of the MP3 player's screen. Three of the screens cannot happen if the MP3 player is working properly. The remaining screen shows the MP3 player when it is working properly.

Which screen shows the MP3 player working properly?



The third item in the unit is classified as *representing and formulating*, since it requires students to form a mental representation of the way the whole system works in order to identify which of four options given shows a state that is possible for this machine. The ability to return the player to its initial state which was present in the first, but absent in the second item of the unit, is again present here, so that the student may interact with the system as much or as little as they need to without restriction. Partial credit was not available for this item and in the field trial it was of similar difficulty to the first item in the unit, with 39% of students selecting the correct response (B).

■ Figure 4.7 ■

MP3 player: Item 4

QUESTION 4

Describe in the box below how you could change the way the MP3 player works so that there is no need to have the bottom button (◀).

You must still be able to change the type of music, and increase or decrease the volume and the bass level.

The final item in this unit is classified as *monitoring and reflecting*, and asks students to consider how the way the machine works might be reconceptualised. This item is one of a small number of constructed response items and requires expert scoring. Full credit answers are those that suggest how the MP3 player might still operate with only one button. There is no single correct answer, and students may think creatively in devising a solution, but the most obvious solution is to suggest changing the way the top button works so that once you reach the right side of the display, one more click takes you back to the left of the display. In the field trial, this was by far the hardest item in the unit, with only 25% of students gaining credit, no doubt due to the requirement for a constructed response and the item's degree of abstraction: students must imagine a hypothetical scenario and link it with their mental representation of how the system currently works, in order to describe a possible alternative functioning. Partial credit was not available for this item.



BIRTHDAY PARTY

■ Figure 4.8 ■

Birthday Party: Stimulus information

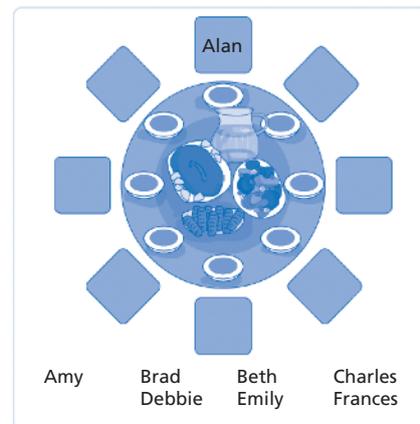
BIRTHDAY PARTY

It is Alan's birthday and he is having a party.

Seven other people will attend. Everyone will sit around the dining table.

The seating arrangement must meet the following conditions:

- Amy and Alan sit together
- Brad and Beth sit together
- Charles sits next to either Debbie or Emily
- Frances sits next to Debbie
- Amy and Alan do not sit next to either Brad or Beth
- Brad does not sit next to Charles or Frances
- Debbie and Emily do not sit next to each other
- Alan does not sit next to either Debbie or Emily
- Amy does not sit next to Charles



The scenario for this unit involves guests at a birthday party who must be placed around the dinner table in a way that satisfies nine specified conditions. The context for the unit is *non-technology* and *social*.

■ Figure 4.9 ■

Birthday Party: Item 1

QUESTION 1

Arrange the guests around the table to meet all of the conditions listed above. Use drag and drop to position the guests around the table.

In the only item in this unit students must drag and drop names to construct a seating plan subject to the nine conditions that are given. The item is therefore classified as *planning and executing*. Since all information that is necessary to solve the problem is given to students at the outset, the item is classified as *static*. Note that the item is *static* only in terms of the definition of the nature of the problem-solving situation. The response format (drag and drop) takes advantage of the capabilities of computer delivery: students can construct, review and revise their solution far more easily than would be possible in a paper-based version of this item. The item has partial credit scoring. For full credit, one of twelve possible solutions that meet all nine constraints must be found (e.g. Alan-Amy-Emily-Brad-Beth-Charles-Debbie-Frances); partial credit is given for solutions that meet only eight of the nine constraints (e.g. Alan-Amy-Emily-Brad-Beth- Debbie- Frances-Charles; here Charles does not satisfy the constraint of sitting next to Debbie or Emily). In the field trial, 54% of students gained at least partial credit on this item, with 43% gaining full credit. The difficulty of this item lies in the large number of conditions imposed, and the reasoning skills required to monitor and adjust partial solutions relative to these constraints until a complete solution is found.



Notes

1. The OECD survey of adult skills defines *problem solving in technology rich environments* as follows: “Problem solving in technology rich environments involves using digital technology, communication tools and networks to acquire and evaluate information, communicate with others and perform practical tasks” (PIAAC Expert Group in Problem Solving in Technology-Rich Environments, 2009, p.7).
2. “Problem solving is an individual’s capacity to use cognitive processes to confront and resolve real, cross-disciplinary situations where the solution path is not immediately obvious and where the literacy domains or curricula areas that might be applicable are not within a single domain of mathematics, science or reading” (OECD, 2003a, p.156).
3. Including those encountered in further education and work contexts.
4. The term “intransparent” is sometimes used to describe problems when complete information about the problem situation is not available at the outset (see Funke and Frensch, 1995).
5. The term “dynamic” is used by some researchers to describe any simulated physical system that a problem solver can interact with and receive feedback. In such cases, a problem situation that changes autonomously is sometimes termed “eigendynamic” (e.g. see Blech and Funke, 2005).
6. See Greiff and Funke (2008) who use the term “MicroDYN” to describe these systems. An earlier implementation of such a system is known as *Dynamis* – see Blech and Funke (2005).
7. Finite state machines for assessment purposes have been implemented under the name “MicroFin” – see http://www.psychologie.uni-heidelberg.de/ae/allg_en/forschun/probleml.html.
8. The two units “MP3 Player” and “Birthday Party” are available for viewing on the web at <http://cbasq.acer.edu.au>, using the credentials “public” and “access”. The interactive nature of MP3 Player can be best appreciated by trying it.



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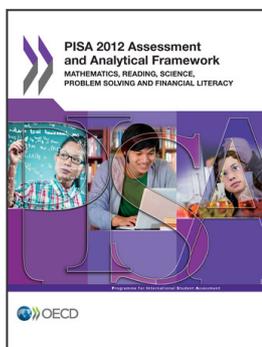
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