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Adaptive problem solving: Moving towards a new assessment domain in the second cycle of PIAAC

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ADAPTIVE PROBLEM SOLVING: MOVING TOWARDS A NEW ASSESSMENT DOMAIN IN THE SECOND CYCLE OF PIAAC

OECD Education Working Paper No. 156

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ABSTRACT

The set of skills that is required to be a successful citizen in the 21st century is rapidly evolving. New technologies and social systems grow increasingly complex and require individuals to quickly and flexibly adapt to new and changing circumstances. This paper outlines the key features of the domain of adaptive problem solving that is proposed to be assessed in the 2nd cycle of the OECD Survey of Adult Skills (PIAAC) in addition to the domains of numeracy and literacy. Adaptive problem solving is considered to be a crucial 21st century skill that combines cognitive and meta-cognitive processes. The paper develops a definition of adaptive problem solving building on relevant work in cognitive psychology and cognitive science, introduces its covariates and preconditions, discusses relevant assessment principles, and provides insights on the relevance of adaptive problem solving for labour markets and social integration.

RÉSUMÉ

Les compétences requises pour être un citoyen accompli au XXIe siècle évoluent rapidement. Les nouvelles technologies et les nouveaux systèmes sociaux deviennent chaque jour plus complexes et demandent aux individus de s'adapter avec rapidité et flexibilité à de nouvelles circonstances. Ce document met en avant les principales caractéristiques de la résolution adaptative de problèmes, qui pourrait être évalué en tant que domaine distinct lors du second cycle de l'Évaluation des compétences des adultes (PIAAC) réalisée par l'OCDE, outre les domaines de la numératie et de la littératie. La résolution adaptative de problèmes est considérée comme une compétence fondamentale du XXIe siècle qui fait appel à la fois à des processus cognitifs et métacognitifs. Le présent document élabore une définition de la résolution adaptative de problèmes en se fondant sur des travaux de recherche pertinents dans les domaines de la psychologie cognitive et des sciences cognitives. Il présente les covariables et les prérequis connexes, analyse les principes d'évaluation pertinents, et offre un aperçu de l'intérêt de la résolution adaptative de problèmes pour le marché du travail et l'intégration sociale.

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SECTION 1: INTRODUCTION

1.1 Why does problem solving matter for adults in the 21st century?

Citizens in the 21st century are faced with complex technologies, social systems and subject matters (NRC, 2012; Levy and Murnane, 2004, 2006; Murnane, Willett, and Levy, 1995). Mastery of facts, procedures, and of the knowledge on how to handle specific tools therefore remains a necessary, but it cannot be considered to be a sufficient condition for participation in a world that demands deeper comprehension of technical material and more complex problem solving, reasoning, information handling and communication.

Today's workplaces demand people who are ready to engage in complex problem-solving activities and, in doing this, solve non-routine problems across diverse situations. Routine tasks require individuals to implement a given set of rules and procedures to be accomplished and therefore are being increasingly automatised. Non-routine tasks, on the other hand, include those problems for which no obvious solution is apparent, and for which the use of repetitive actions is pointless because outcomes and solutions are continuously changing. That is, non-routine tasks usually require at least some amount of problem-solving procedures to be implemented if individuals are to arrive at the envisaged goal state. The OECD Survey of Adult Skills, a product of the Programme for the International Assessment of Adult Competencies (PIAAC), revealed that non-routine problem-solving skills were particularly in demand in the fast-growing, highly skilled managerial, professional, and technical occupations that are on the rise in the 21st century, but also that workers in any occupation were expected to solve non-routine situations to some extent. According to analyses conducted in England, Felstead et al. (2013) conclude that problem-solving skills are more important than numerical or communication skills for a worker to be successful, a finding that is likely to generally apply to economies that are service-oriented.

The ability to quickly and flexibly adapt to new circumstances, learn throughout life, and turn knowledge into action has always been important for full participation in labour markets and society (Pellegrino and Hilton, 2012). However, the characteristics of the typical problems individuals encounter at work and everyday life and their solutions have been changing over the last five decades, in part because of radical changes in digital technologies and communication media (Autor et al., 2003). As computers and computerised machines were introduced in greater numbers in the workplace, workers were needed less often to perform routine manual or analytical tasks. There is evidence of this change in the demand for skills in labour markets in Germany, Japan and the United States, as well as in many other countries and societies (Autor, Levy and Murnane, 2003; Spitz-Oener, 2003; Ikenaga and Kambayashi, 2010).

Information and communication technologies have also become the catalysts of profound changes in the role individuals have in organising their lives outside of work. Governments and companies are able to offer individuals wider choices at lower prices by moving responsibility directly onto consumers. It is often necessary to pay a premium if expert resources are desired. Over the course of a single day, an individual can be a holiday planner, searching for flights and accommodation arrangements (hotels, house swaps, private home location), a financial planner, an architect and a home decorator. Digital technologies are reshaping the constraints and opportunities individuals have to organise their lives and plan for the future in a way that is not routine but usually requires quickly changing, flexible, and adaptive problem-solving skills.

Problem solving has always been an important skill in all societies. However, the bar is now set higher and the proportion of problem-solving activities individuals encounter at work and private life is steadily increasing as a result of technological and social transformations.

This paper summarises the considerations of the PIAAC Expert Group on Problem Solving, which was convened by the OECD Secretariat to develop a conceptual model to guide the development of the problem-solving assessment that could be implemented in the second cycle of PIAAC.

1.2 New literacies: Problem solving in technology-rich environments (PIAAC cycle 1)

When the first cycle of PIAAC was developed, the assessments of traditional competencies, namely literacy and numeracy, were augmented by an assessment of individuals' ability to effectively use information and communication technology to solve problems. Observations of the changing demands for skills and dynamics of skills use in the workplace and everyday life in the 21st century motivated the first PIAAC assessment on problem solving in technology-rich environments (PS-TRE) (OECD, 2012).

PIAAC defined PS-TRE as the ability to "use digital technology, communication tools and networks to acquire and evaluate information, communicate with others and perform practical tasks" (OECD, 2013a). In the PS-TRE assessment, participants were given a series of problem scenarios and were asked to find solutions using ICT-based (information and communication technology) applications such as an Internet browser and web pages, email, word processing, and spreadsheets. In some tasks, solving the problem at hand required individuals to use a combination of different applications. For example, a task might require respondents to use a web-based reservation system to manage requests to reserve a meeting room, and send e-mails to decline requests if reservations could not be accommodated. In general, the PIAAC PS-TRE assessment provided measures of the extent to which individuals are capable of using modern information and communication technology in everyday life and work settings.

The PS-TRE assessment was conceived to monitor individuals' information-processing skills when operating in technology-rich environments, such as the use of digital applications. Evidence from the analysis of the first cycle of PIAAC revealed that some individuals, particularly among older cohorts and adults in some countries, still lack the level of familiarity with computers and ICT technology that is a pre-requisite for developing (and assessing) problem-solving proficiency in technology-rich environments. Proficiency in PS-TRE is associated with an increase in the probability that individuals will participate in the labour market, will be employed, and will receive higher wages - over and above basic literacy and numeracy skills (Quintini, 2014). However, PIAAC highlighted a large degree of heterogeneity in the returns to PS-TRE skills in the labour market: these returns are negligible in occupations that involve little or no ICT skills to perform the required tasks and are highest in occupations that heavily rely on ICT skills (Falck, Heimisch and Wiederhold, 2016).

The PS-TRE assessment provided much needed information on individuals' ability to effectively handle digital information to solve problems, at a time when the effects of the spread of digital technologies had begun to change not only many work environments but also social communication and interactions. It helped to answer important questions on the interrelationship between different literacies, on the distribution of PS-TRE skills both across countries and population subgroups, as well as the benefits that are associated with mastery of such competencies both in isolation and in conjunction with literacy and numeracy.

When the PS-TRE was developed, it was recognised that technological innovations are not only means that individuals need to be able to operate efficiently to be productive and competitive in the labour market or be able to access and use services to go through their daily lives. They are also reshaping the way in which individuals think, access and use information. For example, the rapid expansion of the Internet and social media is increasing the amount of information that is available, although much of such information is unedited, incorrect, and/or contradictory (Rapp and Braasch, 2014).

In fact, the digital revolution has sharply changed the amount of information individuals can access, as well as the cost of accessing such information. Moreover, customisation and new technologies such as smartphones and smartwatches allow us to access information anytime, anywhere. McLuhan's warning that "the medium is message" is as applicable to digital technologies as it was to the electric media that changed how people exchanged information in the twentieth century (McLuhan, 1964). Technologies should not be considered neutral information delivery platforms: they have the power to reshape the way in which individuals think and process information. They demand the use of different strategies to sort, evaluate and prioritise information. The availability of information and on-demand services poses new challenges for individuals' capacity for self-regulation, the ability to persist on difficult tasks, to put the time, effort and energy that is necessary to solve novel problems and pursue long-term goals while avoiding the temptation of non-purposeful information acquisition and entertainment (Duckworth and Gross, 2014; Martin et al., 2013).

Proficiency in the use of specific digital applications to search, manage, interpret, and evaluate information, which were key to the PS-TRE assessment framework, will remain important in 2021 when the second cycle of PIAAC is run. At the same time, the clear need for skills that enable adults to adjust their thinking and reasoning to novel and changing information should be acknowledged in 2021 by developing a broader assessment of adaptive problem solving that goes beyond PS-TRE in some instances. That is, by focusing on technology-rich environments, the PS-TRE assessment ignored (by design) other sets of contexts in which individuals apply their problem-solving abilities. Even more importantly, the PS-TRE assessment identified in ICT the specific operators through which problem-solving tasks were manifested. Therefore the assessment could not provide insights on individuals' capacity to identify, select, and integrate different operators including both ICT and non-ICT operators. In its second cycle, it is proposed that PIAAC should put greater emphasis on the centrality of individuals' capacity to flexibly and dynamically adapt their problem-solving strategies to the environment in which they operate, identify and select among a range of available resources, highlighting the centrality of a reflexive, flexible, and adaptive mind. Furthermore, it is proposed that PIAAC should consider individuals' ability to be open to novelty, to tolerate doubt and uncertainty, and dare to use intuitions ("hunches and feelings") to initiate a solution. These factors are also related to curiosity, perseverance and creativity.

1.3 Towards a domain-general assessment of problem solving

When the PS-TRE assessment was developed, access and use of ICT devices and digital technologies required not only familiarity and willingness to operate in technology-rich environments, but were also intimately tied to a set of technical skills. Operating a laptop computer required a degree of sophistication that today's smartphones and tablet devices do not require to be operated effectively. There is a progressive invisibility of the technology, which allows digital devices to operate with few barriers to entry for consumers. For example, older generations are generally less likely to be familiar with digital technologies than younger generations, and even in a country with wide and deep penetration of digital technologies in the population of over 65, many do not use a computer. However, more seniors own a smartphone, tablet computer, or e-reader than a computer, indicating that they fast-tracked to newer, simple-to-use technology when willing to access digital content (Pew Research Center, 2014). However, just as the importance of technical skills is decreasing for the average user of digital technologies, the relevance of the set of other competencies that are associated with information and communication technologies is continuing to grow.

A large number of proficiencies have been identified as being important to meet the needs of 21st century societies and labour markets, but are infrequently taught in school curricula and are not directly measured by assessments of reading, writing, numeracy, science, and information and communication technology literacy (ICT) (Rychen and Salganik, 2003). These proficiencies include complex problem solving, collaborative problem solving, self-regulated learning, multitasking, communicating through different media channels, retrieving information from large digital repositories, integrating information

from multiple documents, and evaluating the quality of information critically. Assessments are therefore needed to measure these more complex proficiencies in a manner that accommodates the 21st century demands.

The development of touch screens with improved graphic capabilities and vocal recognition technologies is enabling more and more people to search for, access, upload, and use information without having to learn, for example, how to operate a keyboard, a mouse, scroll bars and hyperlinks. These changes, combined with the growth in size and the possible deterioration in quality of the information on the Internet, demand changes in the weight that is assigned in an assessment of problem solving to the ability to operate searches, the ability to devise effective search strategies and the ability to form sophisticated metacognitive strategies for handling information.

Communication with others is a crucial problem-solving task. Communication has increased dramatically in complexity in the past century, as the number and diversity of communication channels increased in the 21st century. Surface mail has, for much of history, been the only means through which communication could take place between individuals who could not meet face-to-face. What changed, over the course of centuries, was the speed and efficiency with which mail could be transported. The landline telephone, the mobile phone and the World Wide Web have introduced a dramatic shift in communication making instantaneous communication with others possible anytime and anywhere.

The PS-TRE and the PISA 2015 collaborative problem-solving assessments (CPS) constitute important sources of information to identify how well individuals are able to use specific communication tools to achieve certain goals (email in PS-TRE and chat in PISA CPS; OECD, 2012; OECD, 2013b). In its second cycle, PIAAC could go beyond this and assess if and how well individuals can select and integrate different forms of information and communication to solve a range of tasks and achieve their goals.

By focusing on technology-rich environments the PS-TRE assessment ignored other sets of contexts in which individuals apply their problem-solving abilities. Even more importantly, by “fixing” the operators through which problem-solving tasks are manifested, the assessment could not provide insights on individuals’ capacity to identify, select, and integrate different resources to solve problem tasks and adapt to potential changes in the problem situation or the information resources. In its second cycle, PIAAC could put greater emphasis on the centrality of individuals’ capacity to adapt their problem-solving strategies to the environment in which they operate and the resources they have, highlighting the centrality of a reflexive, flexible, and adaptive mind.

1.4 Adaptive problem solving in a distributed world

The world of today can be characterised as a distributed world: distributed among technologies, people, and the environment (Dror and Harnad, 2008; Hutchens, 1994; Salomon, 1993). Technological developments that facilitate the efficient storage, retrieval and communication of information enable individuals to offload and distribute some of the functions that they traditionally had to perform. Individuals who are able to reap the advantages that a distributed world offers can extend their capacity beyond the limits of their own cognitive ability. However, in order for individuals to be able to make good use of the possibilities offered by distributing and offloading cognitive demands, they have to master new skills, such as the ability to search for, select and combine resources from their environment. In 2012 the PISA study included a computer-based assessment of creative problem solving. The assessment contained around two-thirds of interactive problem tasks, recognising the increasing necessity for individuals to integrate the knowledge they have with the range of resources that are available to be able to solve problems that they had not encountered before. Students in such assessment were required to uncover useful information in a digital environment by actively exploring the system. In the PISA 2015 assessment of collaborative problem solving students were required to develop social interactions with team members

(simulated as computer agents) to be able to solve a range of problem situations (Graesser et al., forthcoming; OECD, 2013b).

On a more general level, an expert problem solver in a distributed world needs to assess whether a technology, a social community, the external world, or his/her own analytical mind is best suited for achieving particular steps in solving challenging problems combining aspects of creative and collaborative problem solving and acting in a highly adaptive way. This requires a mind shift from the individual problem solver (doing analytical, computational, and quantitative reasoning on their own) to a problem solver who is part of several interconnected and distributed systems in which the social, technological, and physical environments are part of the solutions to difficult problems. Metacognitive proficiencies are involved in the decision individuals take when they decide to trust their own analytical judgment, a computer simulation, social communities, political/legal constraints, and so forth. Questions such as "Should I compute this square root by hand or use a calculator?"; "Should I bake a birthday cake or buy one?"; "Should I talk to this colleague face-to-face or send an email?" are fundamental questions that problem solvers in a distributed system continuously ask themselves. Importantly, the answer to these questions is not apparent and depends on the objectives problem solvers want to achieve, the resources problem solvers have at their disposal and the environment in which they operate.

The core cognitive theories of problem solving (Funke, 2010; Klahr, 2002; Newell and Simon, 1972) can be integrated with the notion of a distributed ecological world. As articulated in the General Problem Solver (GPS) (Newell and Simon, 1972) over five decades ago, any characterisation of problem solving needs to specify the given state, the goal state, the set of legal operators to get from the given to the goal state, and the plans for good solutions to subtasks. These components of problem solving remain relevant in a distributed world. However in a distributed world, the problem solver faces the additional challenge of having to continuously monitor, through conscious effort, whether the current problem state remains the same or changes throughout the course of problem solving, whether operators that are already known from similar problem solving attempts are still available or whether new ones need to be identified, and which plans can be executed using the available resources at a given point in time. The GPS model relied on the idea that once a problem state had been successfully identified and a plan for problem solving had been defined, problem states and plans would change only upon action of the problem solver – with all necessary information contained in the problem description. On the other hand, real-world problem solving in the 21st century resides on the notion that problem solvers need to permanently interact with the environment and monitor how changes in the environment require an adaptation of the problem-solving procedures.

The opportunistic planning model (Hayes-Roth and Hayes-Roth, 1979) can also serve as a theoretical foundation to inform the development of an adaptive problem-solving assessment. The opportunistic planning model assumes that a typical person has multiple problems to solve in the course of a time period and that constraints on the resources, times, and locations of the solutions for each problem constitute, in themselves, an additional problem layer. The problem solver faces a tension and undergoes a challenge because multiple problems (and their solutions) are distributed over time and in different locations. Moreover, resource availability unfolds over time, because resources can be accumulated when some problem tasks are solved and resources are used and consumed to solve other tasks. According to the model, the problem solver is expected to proactively take actions that lead to the accumulation of the resources that are needed to solve problems, to establish priorities and apply sequencing (such as a one-stop shopping for items that contribute to the solution of multiple problems). The problem solver is expected to recognise and capitalise from the appearance of an unexpected resource, which can be used for one or more problems (such as passing by an unexpected yard sale and acquiring items that are needed).

SECTION 2: HOW PROBLEM SOLVING AND ITS COMPONENTS ARE DEFINED

As laid out in the previous section, problem solving (PS) is a complex cognitive activity that enables humans to achieve their goals in situations where no apparent sequence of steps that will eventually lead to the goal is routinely available. The ability to solve problems has been identified as one of the most important human characteristics that helps individuals as well as society as a whole to progress and this holds even more so in a digitalised world in which it is necessary to continuously adapt and flexibly react to changes. Previous PS assessments in PISA and PIAAC have focused on the use of knowledge-rich problems, that is, problems whose solution requires the use of information and knowledge that is not already part of the problem definition.

Here, we suggest continuing with this focus in the next cycle of PIAAC, because the nature of these problems reflects the type of challenges that we face in our private and work lives (see Section 1). We conclude that because of this focus on knowledge-rich problems, a problem-solving model should specifically address the question of how cognitive processes that are required to solve the problem interact with the external world that provides the relevant information to solve these problems, mostly in a digital way. The model of adaptive problem solving introduced in the remainder of this paper conceptualises PS as a process that takes place at the interface between the internal and external world. In this process, the information environment is constantly monitored and problem-solving activities are regulated to accommodate the current status of the environment. In this environment, relevant problem-solving resources are distributed across our physical surroundings, our social context, and the information made available through digital technology. The model of adaptive problem solving emphasises the role of meta-cognitive processes in PS, which assist problem solvers to operate with and co-ordinate among these resources and to flexibly adjust to changing situations or information.

2.1 Problems and their dimensions

A problem is characterised as a situation where there is a difference between a current state of affairs and a to-be-achieved goal state, whereby no means are readily available to reduce this difference (Greeno, 1978; Jonassen, 1997). In other words, a problem entails overcoming a barrier to achieve a goal. Moving from an initial state to a goal state can be accomplished by just recalling past experiences that have made this transition possible (Gick, 1986) or by a routine action (e.g. opening a door using the key). By definition, these activities should not be characterised as problem solving because the move will be accomplished unconsciously by just following the recalled sequence of actions or initiating a simple movement. However, if a human has to engage in intense cognitive processing in order to first understand what the situation is about and then to search for a way of reaching the goal state, then this situation is non-routine and, thus, constitutes a problem.

In the cognitive sciences, various dimensions have been proposed to distinguish different types of problems (VanLehn, 1989). These dimensions are not mutually exclusive. First, problems have been described as either knowledge-lean or knowledge-rich. Whereas for knowledge-lean problems all information required is already included in the description of the problem, knowledge-rich problems require application of background knowledge and/or searching for (additional) information that can be used to understand and to solve the problem. Second, some problems can be solved by just a single action, whereas others require multiple steps to reach a solution. Notably, single-step problems are not necessarily easier to solve than multi-step problems. For instance, insight problems are typical single-step problems

where the problem can be solved with a single flash of thought; however, coming up with this insight involves creative and unusual ways of thinking. Third, some problems are static in the sense that the problem state changes only in response to the problem solver's actions, whereas in dynamic problems the problem state comprises many factors that change independently of the problem solver's actions. The dynamic behaviour of these factors and their interactions makes these problems complex and difficult to solve (Funke, 2010). Finally, problems can be either well-defined in that there is a well specified given state, goal state, and set of operators that can be taken to move from the given to the goal or ill-defined, in which case these aspects are unknown or ambiguous (Greeno, 1978; Jonassen, 1997).

These classifications of problems need to be considered when defining and, in a second step, assessing problem-solving skills. The type of problem situations that have been used in previous large-scale assessment studies attempt to reflect the features that we face when solving real-world problems in our daily lives (cf. Section 1). That is, real-world problems are knowledge-rich in the sense that one needs to reason beyond the given information and make use of information resources in the external world to arrive at a solution. Also most often real-world problems require not just one insight but a series of complex thinking or motor actions to solve them. Finally, problems that we encounter in our daily lives can be static or dynamic and they can be more or less well defined in terms of what constitutes a solution. Table 2.1 provides an overview of the various frameworks of problem solving that have been used in previous international large-scale assessments of problem solving. These assessment studies have predominantly used knowledge-rich, multi-step, static, and well-defined problems.

Table 2.1 Overview of conceptual and assessment frameworks of problem solving in existing international large-scale assessments

Study	Conceptual framework
PISA 2003	**Construct label** Problem solving **Construct definition** "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 curricular areas that might be applicable are not within a single domain of mathematics, science or reading." (OECD, 2004, p. 156) **Key points** • cognitive dimensions of problem solving • cross-curricular nature of assessments. *Problems* • are situated in real-life contexts • are not resolvable through the application of routine solutions • require connections between multiple content areas • draw upon reasoning skills rather than knowledge (OECD, 2005).

Table 2.1 Overview of conceptual and assessment frameworks of problem solving in existing international large-scale assessments (*continued*)

Study	Conceptual framework
ALL 2005	**Construct label** Problem solving **Construct definition** "Problem solving is goal-directed thinking and action in situations for which no routine solution procedure is available. The problem solver has a more or less well defined goal, but does not immediately know how to reach it. The incongruence of goals and admissible operators constitutes a problem. The understanding of the problem situation and its step-by-step transformation, based on planning and reasoning, constitute the process of problem solving." (Murray, Clermont and Binkley, 2005, p. 197) **Key points** • cognitive dimensions of problem solving • context, scope, and complexity as core characteristics of problems. *Problems* • are situated in real-life contexts • require a set of problem-solving steps • are designed as projects.
PISA 2012	**Construct label** Creative problem solving **Construct definition** "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." (OECD, 2013c, p. 122) **Key points** • Cognitive and affective dimension of problem solving. *Interactive problems* • Require the exploration of the situation to uncover additional relevant information. *Static problems* • Provide problem solvers with complete information about the problem at the outset.

Table 2.1 Overview of conceptual and assessment frameworks of problem solving in existing international large-scale assessments (*continued*)

Study	Conceptual framework
PIAAC 2012	**Construct label** Problem solving in technology-rich environments **Construct definition** "[…] problem solving in technology-rich environments is defined as: using digital technology, communication tools and networks to acquire and evaluate information, communicate with others and perform practical tasks. The first PIAAC problem-solving survey focuses on the abilities to solve problems for personal, work and civic purposes by setting up appropriate goals and plans, and accessing and making use of information through computers and computer networks." (OECD, 2012, p. 47) **Key points** • reference to the ability to solve information problems • focus on the active construction of goals and strategies of problem solving • digital technologies have a critical role. *Information problems* • can result from the availability of digital technologies • can be solved with the help of digital technologies • are related to the handling and maintenance of technology-rich environments.
PISA 2015	**Construct label** Collaborative problem solving **Construct definition** "Collaborative problem-solving competency is the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution." (OECD, 2013b, p. 6) **Key points** • collaborative problem solving comprises collaborative *and* problem-solving skills • primary focus is on collaboration.

2.2 The process of problem solving

In their seminal work on the General Problem Solver (GPS), Newell and Simon (1972) defined the process of PS as follows: "a given state is transformed into a goal state by applying a sequence of consciously selected actions." PS requires that not *all* action selections are carried out unconsciously or automatically and that there is no obvious or routine solution to bridge the initial state and the goal state (Mayer and Wittrock, 2006). According to Mayer and Wittrock (2006), PS can be characterised by four

main features: It is a *cognitive* process that occurs internally within a person's information-processing system. Therefore, information-processing resources (such as attention or the capacity of the human mind to store and manipulate different types of information simultaneously, i.e. working memory) are important to PS success (Wiley and Jarosz, 2012). Likewise, PS is a *process* that is based on representing and manipulating knowledge structures. Therefore, PS success depends on what a person already knows about the problem at hand and thus can bring to the task of solving it (Goode and Beckmann, 2010). Moreover, PS is *directed* towards a goal, and finally it is *personal* in the sense that a person's knowledge and skills determine the ease with which a problem can be solved (Funke, 2010).

According to Newell and Simon (1972), PS is defined in terms of a series of state transitions in a problem space, which is characterised by states and transitions from one state to another. A problem space is represented at various levels of grain size and detail. It consists of an initial state, a goal state, and intermediate states, each of which exists in the route between the start state and the goal state (Newell and Simon, 1972). In order to solve a problem, a person has to define the problem by constructing a mental representation of the initial and goal state of the problem. Then he or she has to search for a sequence of intermediate goal states that will eventually lead from the initial to the goal state and determine the sequence of operators that will help to achieve the subgoals and serve to make the transitions between subgoals. In this search, process constraints imposed by the environment need to be considered, since they determine which operators are available and can be applied to solve the problem. The sequences of operations can be chunked into plans that service a sub-goal. These plans can then be executed by applying the operators. During the application phase impasses may occur that prevent a problem solver from achieving the desired sub-goal. In this case, plans need to be revised and new sub-goals and the operators serving them need to be defined. Especially in knowledge-rich problems it is unlikely that a problem solver figures out an entire plan in advance and executes it mechanically; rather, s/he will switch between searching for a solution, executing operators to achieve a sub-goal, and searching again. Similarly, dynamic problems make it impossible to figure out comprehensive problem-solving plans in advance; rather, a problem solver has to continuously adjust his solution procedure to the changing constraints imposed by the environment. Nevertheless, the stages – problem definition, searching for a solution, and application – are constituents of every problem-solving process regardless of the type of problem to be solved and the environment in which it takes place (see also Figure 2.1).

Newell and Simon's (1972) model was initially developed with respect to solving knowledge-lean problems. Nevertheless, their research has laid the foundation for much of the research on problem solving in the cognitive sciences also for knowledge-rich problems, that is still of relevance today and where among other things it has been used to describe the process of scientific discovery and learning through scientific reasoning (e.g. Klahr, 2000; Klahr and Dunbar, 1988; Vollmeyer, Burns and Holyoak, 1996). However, partly due to its origin in the context of knowledge-lean problem solving, the GPS model lacks some aspects necessary to describe problem solving in the 21st century in a comprehensive manner. Thus, in the following sections we analyses the differences between the problem-solving situation that built the basis of the GPS model and the one that we are now facing when solving real-world problems in a digital world. Based on this analysis, we describe a broader notion of problem solving, which incorporates the GPS model, but expands it with regard to three (not mutually exclusive) aspects.

The model of adaptive problem solving introduced in Figure 2.1 shares this characterisation of problem solving, but expands with regard to each of the four aspects:

- First, APS is not only seen as a cognitive but also a metacognitive process.
- Second, APS emphasises that even though the problem solving processes rely on the manipulation knowledge, it is key to acknowledge the centrality of individuals' ability to select and organise the sources of knowledge, namely, the physical, social, and digital environment

problem solvers encounter. This implies that even though the APS process is an individual act, successful APS depends not only on an individual's internal resources, but also on the accessibility of external resources and the way a problem solver can make use of them.

- Finally, although both PS and APS are goal-directed; adaptive problem solvers recognise and acknowledge that, given today's ubiquitous access to information, there are often situations in which there are opportunities for solving multiple goals. Such opportunity determines a new need for problem solvers: the capacity to manage multiple goals and make decisions about when to pursue a certain goal or switch one's problem-solving efforts to achieve a different goal.

As a first extension to the model of Newell and Simon, it has been emphasised that we hardly face only one problem at once; rather, we often need to solve multiple problems in parallel, which requires us to manage the order in which we approach these problems and to monitor opportunities that arise for solving these problems (opportunistic planning, Hayes-Roth and Hayes-Roth, 1979). Given the ubiquitous access to a large body of digitally available information, there are always challenging problems that we face and we often immediately have access to many relevant resources for solving these problems. Hence, we may be tempted to shift attention from one problem to the next too quickly or to solve multiple problems in parallel (cf. multitasking), which humans are not good at. As a consequence of the ubiquitous access to PS resources, we need to become better managers of our goals (Hirashima et al., 1997). That is, we need to monitor our environment for opportunities to solve problems, adapt our goals according to these opportunities, while at the same time avoiding the costs of task shifting and multitasking (Scheiter, Gerjets and Heise, 2014). Notably, the need for adequate goal management is likely to have become more relevant with the increasing availability of digital information. When there was only the physical and social environment, one was able to work on those problems for which the current configuration of these environments provided the necessary resources (e.g. one could not fix a machine without being in a garage with tools being present). In the digital environment these constraints have been substantially relaxed in that one can find helpful information for almost every problem; thus, the temptation to switch between multiple problems is greater.

Second, real-world PS is not an exclusively internal information process; rather, solving knowledge-rich problems relies on interacting with the external world and making use of the information resources that this world provides. Hence, PS is much more distributed among technologies, other people, and the environment (cf. Dror and Harnad, 2008; Hutchins, 1994; Salomon, 2003) than what was initially captured in the model of Newell and Simon (1972) over four decades ago. The notion of adaptive problem solving introduced below heavily relies on the idea that PS is based on an interaction between internal cognitive processes and the external world (see Figure 2.1). Ubiquitous access to digital information provides a great resource of many everyday PS activities. This can make PS far more efficient than before. In the PS-TRE assessment in the first PIAAC cycle (OECD, 2012), a focus was put onto the use of digital information resources. We still believe that ubiquitous access to digital information plays an important role for problem solving and will continue to do so in the near future. However, based on the presence and also on our expectations for the future, it is likely to lose its special status; rather, it will become one self-evident resource available for problem solving – beyond our physical and social environment. Because the digital world is seamlessly integrated in our everyday lives, the challenge is to decide which of the resources (or combinations thereof) should be used for solving a given problem in a distributed setting. Thus, problem solvers need to adapt their choice of physical, social, and digital resources to the problem that they face, which, in turn, requires a good understanding of what the problem is about and of the most effective operators for solving it.

As a consequence of the need to manage the PS process for multiple problems and with multiple resources, we conceive PS as a challenge that no longer relies on cognitive processes alone. Instead, problem solvers need to continuously monitor how well their PS activities are aligned with the current state of the external world and the resources it makes available to them as well as to regulate their problem solving accordingly. Monitoring and regulation of (higher-order) cognitive processes towards goal achievement is achieved through metacognition (Hacker, Dunlosky and Graesser, 2009; Nelson and Narens, 1990). Meta-cognitive processes thus allow problem solvers to behave adaptively (Bohle Carbonell et al., 2014). Below we will describe the concept of adaptive problem solving, as it presents itself in the digitalised world of the 21st century, in more detail.

2.3 Adaptive problem solving – an overview

Adaptive problem solving (APS) takes place at the interface between the internal, mental world of the problem solver and the external world that makes information available in the physical, social, and digital environment that can be used as problem solving resources (Figure 2.1). Mayer (2014) defines APS as "a form of problem solving that requires a series of problem reformulations or continual re-evaluation of problem formulations in light of changing conditions. In short, adaptive problem solving occurs when a problem solver continually revises how he or she represents the problem (and its solution plan) in light of the changes in the problem situation" (p. 153). Such changes in the problem situation that require a revision of one's problem-solving plans are more likely to occur in a digitalised world where information is highly volatile. Cognitive problem-solving processes can be adjusted to the information environment with respect to at least three major aspects.

- First, goals (i.e. to-be-solved problems) can be switched based on favourable opportunities for acting upon these goals that arise in the information environment (Hirashima et al., 1997; Scheiter et al., 2014).

- Second, the problem-solving process can be flexibly adjusted to the different resources that the information environment provides, which will affect the choice of operators to solve a problem (e.g. asking a friend vs. asking Google®).

- Third, any of the three stages of problem solving (i.e. definition of a problem, searching for a solution, and application, depicted from left to right in Figure 2.1) can be adjusted in response to changes that occur in the information environment.

Any change in information may require that a problem solver redefines the problem or redesigns a plan and hence returns to a previous stage in the problem-solving procedure as indicated by the reverse arrows in Figure 2.1. Importantly, being adaptive always involves a trade-off between perseverance and flexible action. That is, an adaptive problem solver will often need to decide whether to stick to or to choose another problem, resource, or plan. These decisions can be challenging and may require consideration of many variables such as the likelihood of encountering a favourable opportunity for pursuing an alternative goal in the near future or the costs for interrupting the problem-solving process for the initial goal (Heise, Gerjets and Westermann, 1997).

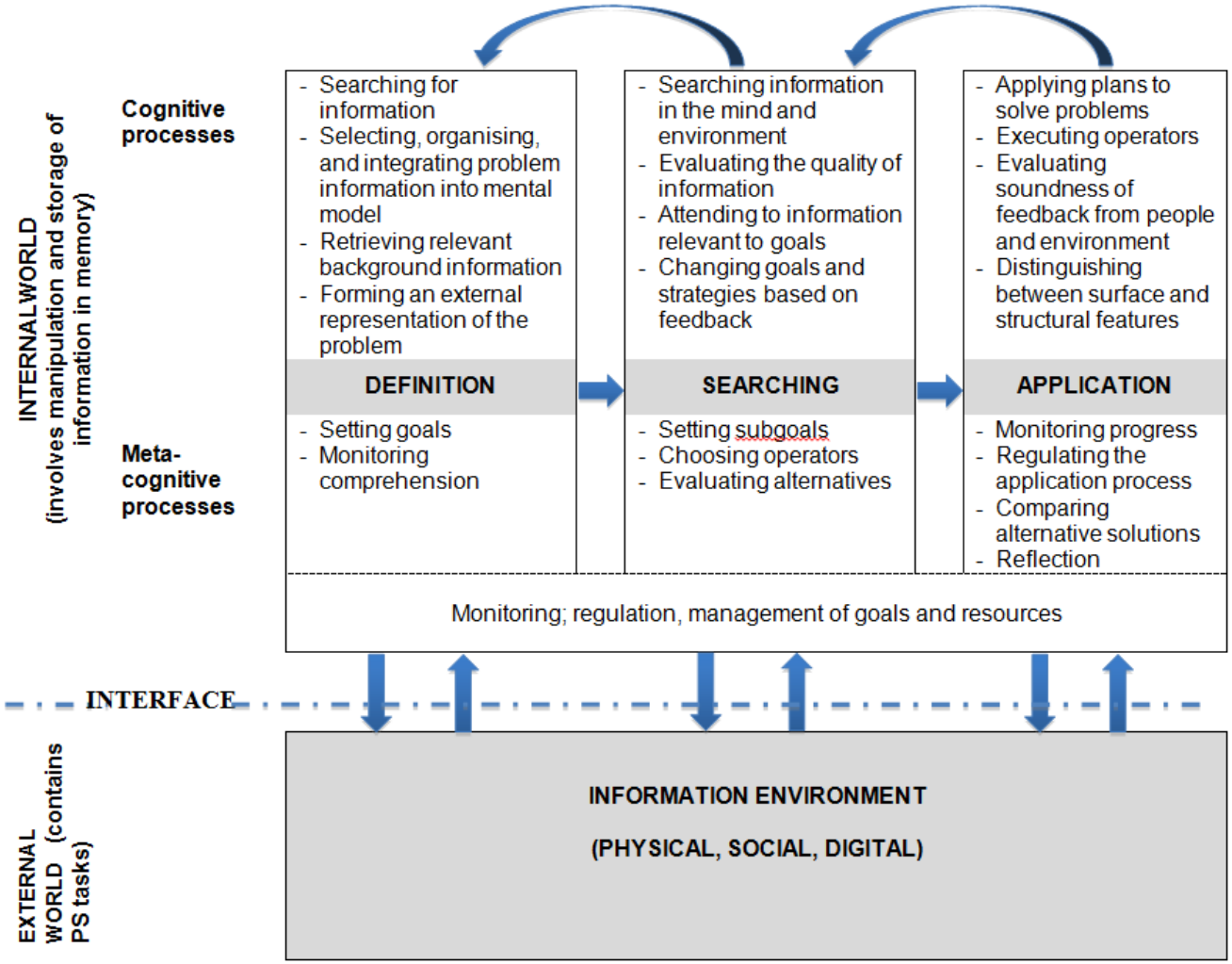
APS does not imply that problem solvers will always strive for or reach the solution that is optimal from a normative or rationale standpoint. That is, they are not seen as agents acting in a perfectly rational manner. On the contrary, the concept of APS relies on the notion of satisficing and bounded rationality (Gigerenzer and Selten, 2002; Simon, 1990; Tversky and Kahneman, 1973). Thus, problem solvers are expected to plan and conduct the solution process relative to the resources (e.g. time, effort) that they are willing to invest in solving a particular problem. Accordingly, problem-solving goals with little personal relevance will result in problem-solving strategies that do not require a lot of resources (e.g. superficial

WWW search strategies) and that will likely yield a solution that suffices minimum standards only. Moreover, bounded rationality in APS is due to the fact that humans' information processing is influenced by a wide range of cognitive and motivational biases (Tversky and Kahneman, 1973). For instance, humans are more likely to accept information as true that is more accessible in memory (availability bias), to prefer information that confirms their own views (confirmation bias or myside bias), or wrongly estimate the frequency of occurrence of features or events (representativeness bias). Moreover, motivational biases (e.g. the wish to protect oneself against harm) have been shown to influence information search, especially when the goals to be achieved are of high personal relevance (e.g. finding optimal treatment for a health issue; Greving and Sassenberg, 2015). While Tversky and Kahneman (1973) emphasised the errors in humans' information processing that occur due to biases and the use of heuristics, others have emphasised that especially the use of heuristics is what makes humans smart by allowing them to come to fast (albeit possibly biased and sometimes incorrect) decisions in an often complex and uncertain world (Gigerenzer, Todd and the ABC Research Group, 1999).

The concept of APS sees problem solvers as agents with bounded rationality, whose use of heuristics has a strong effect on problem solving. Importantly, bounded rationality has become more important in the digital age: First, the vast amount of information almost makes it impossible to identify and process all relevant information when there are only limited resources available. That is, satisficing underlies many APS activities and (effective) heuristics are mandatory for being able to act in the digital world. Moreover, the structure of the digital environment influences the ease with which we use heuristics without even knowing. For instance, intelligent search engines, recommender systems, and filtering mechanisms in social media can increase the impression that our own opinions are supported by the available information (i.e. we are living in a 'filter bubble'), thereby enhancing confirmation bias. On the other hand, the digital environment gives minorities the opportunity to express their views and make them available to the public; moreover, it provides access to information that was previously used by elites only (e.g. experts, scientists). Thus, in the digital age, problem solvers have a lot more information available that allows them to come to more balanced and better decisions.

In order for problem solving to be adaptive, meta-cognitive and self-regulatory processes are highly relevant (O'Neil, 1999). The information environment needs to be constantly monitored and cognitive processes need to be regulated with respect to the current status of the information environment. Similar to the management of goals and resources, monitoring and regulation are constant demands in APS. In addition, there exist other meta-cognitive processes that are more specifically tied to the different stages of problem solving, which will be described below.

Figure 2.1 Conceptual model of adaptive problem solving



2.4 Stages of adaptive problem solving

APS involves three major stages, namely, defining a problem, searching for a solution, and applying a solution (Gick, 1986; Newell and Simon, 1972) - depicted from left to right in Figure 2.1. Each of the stages can be characterised by different cognitive (upper part of the figure) and meta-cognitive processes (lower part of the figure) with the latter being an extension to Newell and Simon's PS model as well as to previous assessments of problem solving, which mainly emphasised the cognitive aspects (OECD, 2013c; Wang and Chiew, 2010). This augmentation is necessary in order to account for the adaptive nature of problem solving in today's digitalised world, where a problem solver has to continuously monitor any changes that will occur in the external world and regulate his/her problem-solving actions accordingly. For instance, imagine that a person plans to go on a holiday to the seaside. After having already constrained the Internet search to the Italian coast s/he is in the course of searching for an affordable flight+hotel offer, when an email advertisement makes him/her suddenly aware of a bargain offer for an all-inclusive stay in a hotel at the Egyptian coast. Considering this alterative will require evaluating the offer in terms of whether it fulfils the goal definition (seaside, affordable price, safe place) and readjusting the search for a problem solution, which now requires finding a cheap flight to Egypt rather than a flight+hotel in Italy, while taking into account that flights to Egypt will be more expensive than to Italy.

It is important to conceptualise problem solving within the broader realm of other higher-level processes (e.g. decision-making, reasoning, comprehension) such as information processing, where information needs to be perceived, selected, and organised in working memory, integrated into more comprehensive mental structures, and then brought to action. Basic processing resources such as attention, working memory, and executive functions are all likely to influence problem-solving activities. These basic processing capabilities are important and should possibly be assessed as individual characteristics contributing to problem-solving success in PIAAC. That being said, they play a less discriminating role in defining the specific complex cognitive and meta-cognitive processes involved in problem solving. Rather, they are generic features of the human cognitive architecture relevant to performing most cognitive tasks and they are considered important antecedents of adaptive problem solving. Thus, the following description that is organised according to the three stages of problem solving will focus on an intermediate level of detailing cognitive and meta-cognitive processes that addresses the functions that each process plays for solving the problem.

Problem definition

At the cognitive level (depicted in the upper part of Figure 2.1), the process of defining the problem requires that a person constructs a situation model of the state of affairs described in the problem (Mayer and Wittrock, 2006; Nathan, Kintsch and Young, 1992). This situation model comprises information on the initial state, the goal state to be achieved, the legal operators, and the set of intervening states that are required in order to move from the initial state to the goal state; together these various states make up the problem space (Klahr, 2000; Klahr and Dunbar, 1988; Newell and Simon, 1972; Vollmeyer et al., 1996). The creation of a situation model requires factual and conceptual knowledge (Mayer and Wittrock, 2006). Its adequacy is pivotal for solving the problem since it determines all further problem-solving activities.

There are a number of different cognitive processes that come into play at this first stage of problem solving that are listed in Figure 2.1. In order to construct a comprehensive mental representation (or sometimes called the situation model; Kintsch, 1998) of the problem, one first needs to gather information that might be relevant to the solution of the problem. The exploration of information will be rather broad and involve the use and evaluation of multiple sources of information as resources with respect to their reliability, relevance, adequacy, and comprehensibility. For instance, consider the aforementioned holiday example, where Internet portals of different trustworthiness, email alerts, but also recommendations of friends will constitute relevant resources to consider in one's problem definition. Importantly, top-down

processes may already come into play at this very early stage of dealing with the problem. That is, a person needs to perceive the current physical situation through his/her sensory organs under some attention scheme. The sensors' performance might differ among people and therefore different representations of problem space may result. Moreover, information search may be biased (Tversky and Kahneman, 1973).

To construct a situation model of the problem, relevant information needs to be selected from the facts collected about the problem, organised and integrated into a coherent mental representation that will suit to serve the solution of the problem (Mayer, 1996). These processes imply that a person retrieves relevant background knowledge that helps distinguishing between relevant and irrelevant information as well as building a coherent situation model. Memories from past problem-solving activities are one important source of background knowledge. Thus, a problem solver has to activate these memories from past problem-solving activities, which has been shown to be difficult for many problem solvers who fail to be reminded of these past recollections and do not recognise that they possess potentially helpful past experiences (Ross, 1989a). Moreover, during this memory retrieval process but also when constructing a situation model from scratch, many problem solvers will fail to distinguish between a problem's structural features that will affect how the problem can be solved and superficial or contextual features that are irrelevant to its solution (Braithwaite and Goldstone, 2015; Ross, 1989b). Therefore, they will activate memories of past problems that are only superficially similar to the problem at hand or construct a situation model that is heavily based on irrelevant information, which will misguide the subsequent problem-solving steps.

It is important to note that the process of searching for relevant information in the external world as well as memory activation processes have to be carried out within the available time, which is controlled at a meta-level. On the one hand, search and activation processes may become more accurate in terms of finding the most relevant information when investing more time in them. On the other hand, investing too much time in these processes can render the definition of a problem highly inefficient. Thus, speed-accuracy trade-offs need to be considered at this stage of problem definition. Cognitive biases may be an efficient, albeit error-prone strategy to reduce the time and resources required for careful information search.

Even though problem solving itself is mostly an internal process (Mayer and Wittrock, 2006), it can largely benefit from externalising one's thoughts. With respect to the construction of a situation model, problem solving will benefit from forming an external representation of a problem's main features (e.g. in a drawing or table; Ainsworth, Prain and Tytler, 2011; Fischer, Greiff and Funke, 2012; Zhang, 1997). From an assessment perspective, these externalisations can provide important insights into the way a person conceptualises a problem, his or her misconceptions or gaps in the situation model (Lee, Jonassen and Teo, 2011).

There are many factors that can contribute to the difficulty of coming up with an adequate solution model of the problem: The information about a problem can be incomplete, it may require considering multiple factors simultaneously, these factors can interact with each other, they may change over time and at different time scales. With respect to the latter point, the construction of a situation model is not a process that, once accomplished, serves as a constant grounding for further problem-solving steps. Rather, a problem solver needs to continuously monitor whether there is new information that is potentially relevant to the construction of the situation model (e.g. incoming email alerts, website updates, etc.). This information can either be assimilated (i.e. added to the current situation model in order to refine it or make it more complete) or lead to an accommodation of the situation model, that is, a reconceptualisation of one's understanding of a problem (cf. Piaget, 1977). As a consequence, the notion of APS implies that a situation model requires continuous updating (Mayer, 2014).

The aforementioned sub-processes during the creation of a situation model refer to the cognitive layer of problem solving. However, their regulation requires additional meta-cognitive processes shown in the lower part of Figure 2.1. In particular, a problem solver needs to set a goal as to how much information s/he wishes to gather in order to construct a situation model and needs to monitor whether his or her understanding of the problem is sufficient in order to find a solution to it. An accurate comprehension monitoring is especially important, since it will determine whether the process of constructing a situation model is adequately controlled (Nelson and Narens, 1990). That is, overconfidence in one's understanding of the problem may lead to a premature termination of the search for problem-relevant information, whereas under-confidence may yield an inefficient construction process, where information search is continued even after all relevant information has been identified. Research on meta-cognitive judgments has shown that many people, especially those with little prior knowledge, make rather inaccurate judgments of their level of comprehension and rely on invalid cues when making these judgments (Bjork, Dunlosky and Kornell, 2013).

It can be argued that in the 21st century the construction of a situation model still involves the same cognitive sub-processes as before digitalisation of our environment took place. However, meta-cognitive demands have increased due to the ubiquitous availability of large amounts of information, which is moreover volatile. That is, problem solvers have to evaluate the quality of much more and more heterogeneous information when attempting to solve problems with the help of the World Wide Web (WWW). On the one hand, the availability of large amounts of information combined with the alleged ease of searching information using powerful search engines such as Google® may lead to overconfidence in that problem solvers are already confident to have found all necessary information regarding a problem after having studied only the first two to three results of their search query. On the other hand, problem solvers may get lost in the process of searching for problem-relevant information in that they get derailed by irrelevant information and fail to stay on track during their information search. Due to the volatility of the available (digital) information coming up with an accurate problem definition is not a process that once done is finished; rather, the problem definition needs to be constantly evaluated whether it still aligned with the current state of the information environment or whether it requires adaptation. Since the advent of the WWW it has become impossible to process all available information, efficient strategies of gathering information as well as sound criteria of when a satisficing result (Simon, 1990) has been achieved are called for. Thus, accurate comprehension of a problem as well as regulation of one's cognitive processes on a meta-cognitive level towards adequately representing the problem state have become much more challenging when attempting to solve problems by making use of the information resources that the 21st century has provided us with. As a consequence of the large amounts of available information, problem solvers always need to monitor and regulate their problem-solving processes relative to the time that they have available and can reasonably spend on each process. Hence, they need to consider the trade-off between finding an optimal solution (accuracy) and the costs (speed) for doing so.

Searching for a solution

The second component, searching for a solution, relies heavily on the knowledge about the problem's structure that was derived during the first component of defining and understanding the problem situation. The solution of the problem can be described in terms of a sequence of steps necessary to get from the initial state of the problem to the goal state. Finding a solution can either involve domain-general problem-solving strategies such as means-end analysis, or domain-specific strategies such as solving an equation in the domain of Algebra (O'Neil, 1999).

The process of searching for a solution marks the distinction between a task and a problem. A task is present if a solution can be directly retrieved from memory and applied to the situation at hand effortlessly and without modification. A problem, on the other hand, requires that a person breaks down a problem into parts, searches for a solution among different alternatives, plans a sequence of actions, and possibly tries

out different ways of reaching the goal state (Gick, 1986). The search for a solution thus requires strategy knowledge on different solution methods and the meta-cognitive skills to handle this knowledge (Fischer et al., 2012; Mayer and Wittrock, 2006).

At the cognitive level (upper level of Figure 2.1), this stage requires searching information in the mind and environment and evaluating the quality of information with respect to how well it serves a possible solution of the problem. Moreover, a problem solver has to attend to information relevant to goals.

The following meta-cognitive processes (lower level of Figure 2.1) characterise the stage of finding a solution. First, finding a solution involves planning the problem-solving process by generating a hypothesis regarding the sequence of subgoals (intervening problem states) or setting subgoals that need to be reached in order to make the transition from given to goal state and to choose the operators (procedures, tactics, strategies) that will be suited to make this transition happen (cf. dual space theory, Klahr and Dunbar, 1988; see also Greiff, Wüstenberg and Avvisati, 2015). In many cases, there will not be just one possible sequence of sub-goals and operators; rather, there will be alternative solution methods that need to be evaluated against each other regarding possible costs, success probabilities etc. Especially with complex problems (such as problems that are characterised by a large problem space) it can be helpful to externalise plans by writing down or sketching the sequence of sub-goals and operators. Searching for a solution also involves selecting appropriate devices, tools or information and communicating and co-ordinating one's activities with other parties (cf. collaborative problem solving; OECD, 2013a). APS in the 21st century requires that problem solvers constantly update their knowledge about viable, meaningful, and efficient operators. For instance, in former times, information search may have always involved going through the library's index catalogue. Nowadays, a search strategy may involve using Google®, forums and web portals, and social media, information sources that are more ephemeral-lived than the library catalogue.

In most cases, there will be interplay between searching a solution and the representation of the problem in a situation model. On the one hand, planning a solution will likely make a problem solver aware of the fact that s/he is missing important information about the problem in order to adequately devise a solution method, which will affect his or her monitoring in the problem definition stage as well as stimulate further information search activities. On the other hand, planning a solution method will be successful only to the extent that a problem solver has available the most recent representation of the problem. Thus, during the planning phase, the situation model has to be continuously inspected and possible updates have to be considering when devising a solution to the problem.

Moreover, the process of finding a solution rarely results in an entire plan for solving the whole problem; rather, problem solving plans need to be adjusted based on the experiences made during applying operators in the third and final stage (see below). In particular, impasses encountered in this stage may require a problem solver to change goals and strategies based on the feedback obtained from executing a plan, thereby behaving adaptively.

Applying a solution

During this third stage, at a cognitive level, a problem solver applies plans to solve a problem and executes the specified operators. This stage relies on having procedural knowledge available (Mayer and Wittrock, 2006). The nature of this procedural knowledge will depend on the requirements of the problem and may for instance comprise Algebra skills to solve equations, logical reasoning skills, or other domain-specific operators.

At a meta-cognitive level, during executing a problem-solving strategy, one needs to constantly monitor the degree to which progress towards solving the goal has been made (progress monitoring). To do so, it is important that the goal has been defined in a way that clear criteria for goal achievement exist

against which the current problem state can be evaluated. For progress monitoring, information from the environment needs to be considered. In the case where the goal state has been achieved, the problem-solving process can be terminated. However, monitoring will often lead to the detection and interpretation of unexpected events, impasses, or breakdowns. If there is no or too little progress towards the goal state, problem solvers will need to identify possible reasons for this in order to regulate their future efforts accordingly. A problem-solving failure may either be due to the fact that the plan itself was inadequate, in which case a modified or entirely novel plan has to be devised, thereby back-tracking to earlier stages of the PS process. Alternatively, the plan may have been adequate, but a problem solver may have failed to carry out the involved operators, because s/he lacked the procedural knowledge. In this case, the formerly devised plan can still be used to solve the problem, but its execution needs to be optimised. Accordingly, different reasons for APS failure will require different types of regulating the problem-solving process (i.e. plan revision vs. execution optimisation). People who are good at solving problems have been shown to reflect upon their problem-solving experiences and abstract strategy knowledge from it that can be put to use in future problem-solving situations. Thus, PS is assumed to leave memory traces, which can be used in the future.

2.5 Variability of processes as a function of problem type

The aforementioned cognitive and meta-cognitive processes may have specific forms across different types of problems (Jonassen, 2011). For instance, whereas decision-making problems demand a clear and reasoned argumentation of a problem, that may or may not have a straightforward solution (Heitmann et al., 2014), trouble-shooting problems demand the understanding of the abstract problem space in order to reason on the failure of a given system (Leutner et al., 2012). Along the same lines, information problems require the identification, use, and evaluation of information.

In the present section, a model of problem solving was introduced that emphasises the role of adaptivity in problem solving. According to the model, adaptive problem solving takes place at the interface between a person’s cognitive and meta-cognitive processes and the external information environment. This environment consists of the physical, social, and digital world that provides us with resources for problem solving. Adaptivity in problem solving means that this environment is constantly monitored and the process of problem solving (i.e. definition of a problem, searching for a solution and application) is regulated according to the results of this monitoring process. In addition, adaptivity entails that we need to manage our goals relative to the opportunities that arise for solving them and make flexible use of the different resources made available in the information environment that surrounds us.

SECTION 3: COVARIATES AND PRECONDITIONS OF ADAPTIVE PROBLEM SOLVING

A number of cognitive and non-cognitive processes are important for successful APS. In fact, the absence of some relevant preconditions might hinder the problem-solving process, or even render it fully impossible. As discussed in Sections 1 and 2, APS often involves attempts to handle multiple problems in parallel by monitoring, manipulating, and regulating progress of external and internal states and by interacting with an external world that is in many ways digitalised. This extension of the understanding of problem solving as a largely adaptive process (see Section 1 and Figure 2.1) can co-vary with other cognitive processes and relies upon, and is preceded by, a number of further cognitive and non-cognitive processes.

Given the complexity of problem solving and the processes associated with it, the list of potentially relevant covariates and, even more so, preconditions are long. It is therefore important to distinguish those skills that are preconditions because they are distinctively relevant to APS in particular from those that are covariates with a large number of knowledge domains and proficiencies. That is, a precondition of APS is a cognitive or non-cognitive process that is needed in order to engage in the process of problem solving and that might hinder or facilitate it, whereas a covariate to some degree shares preconditions and processes with APS, but is on the same level rather than a precondition. For instance, as outlined below, literacy (and, for that matter, numeracy) is a covariate of APS and the two even share some processes that are conceptually relevant both for literacy and APS such as evaluating information in a text (while, at the same time, they also have a large portion of processes that are distinct). However, literacy is not a precondition of APS and vice versa, but basic reading skills are a necessary precondition for all literacy tasks and for at least some APS tasks.

3.1 Literacy and numeracy as covariates of APS

As mentioned in the previous example, the arguably most important covariates of APS in the context of the PIAAC assessment are literacy and numeracy. Put differently, literacy and numeracy are two competencies that share some (not all) processes with many other domains and skills that are assessed, one of them being APS (Greiff et al., 2014). In the first cycle of PIAAC literacy was defined as the ability to "construct meaning from a text", "making judgments about texts," and "directed towards applying information and ideas in a text to address an immediate task or goal or to reinforce or change beliefs" (OECD, 2012). Consequently, tasks in the PIAAC literacy assessment required adults to "locate items of information in a text", "understand the relation(s) between different parts of a text", and to "evaluate and reflect on text by drawing "on knowledge, ideas or values external to the text" and assessing "relevance, credibility" or "purposefulness, register, structure" (OECD, 2012). In most of these tasks, the focus is on an analysis or evaluation of the text.

To better understand the notion of covariates, it is relevant to consider that some of the cognitive and metacognitive processes that are necessary for individuals to be proficient in literacy are equally important to determine proficiency in APS. For example, when a problem is presented in language form, problem solvers have to correctly decode the information and make inferences to represent the described situation. If a problem-solving task is (partly) presented in a language format some proficiencies in language and basic reading skills are obviously required (OECD, 2015), but the ensemble of language skills is not equivalent to those skills in the literacy assessment. Above and beyond that, literacy then is one aspect of the problem-solving process and both, literacy and APS co-vary with each other. It is important to note the

fundamental difference between literacy as a skill that is located on the same level of abstraction as APS and basic reading skills. The latter are a precursor for APS (and, obviously, for literacy as well) because they are needed already for understanding the problem situation and for being able to mentally decode its components and the information given. That is, basic reading skills are precursors but analysing and evaluating a text along the understanding of literacy is not per se a precursor skill to APS.

Similarly, when a problem has numbers or graphical representations, problem solvers need to have some skills that allow them to comprehend the graph. They also might need some understanding of numerical information such as simple math competencies. Those are considered precursors of APS as well. However, these basic skills are in contrast to the understanding of numeracy as a higher-order thinking skill as defined in the first cycle of PIAAC. There, numeracy was defined as one's "ability to access, use, interpret and communicate mathematical information and ideas in order to engage in and manage the mathematical demands of a range of situations in adult life" (OECD, 2012). Numeracy tasks require readers to "identify, locate, or access"; "act upon or use"; and "interpret, evaluate/analyse, communicate" (OECD, 2012). In problem solving, one may have to use knowledge of numbers or skill with numerical formulas or graphical representations, but these are instrumental skills to solve a problem and not the end point.

It is proposed that in the second cycle of PIAAC all three domains (literacy, numeracy, and APS) will be assessed and that literacy and numeracy will be considered as important covariates of APS. In addition to this, the relation between ICT literacy and problem solving in the digitalised world of the 21st century is of high relevance in APS and will be separately targeted in Section 6 because for APS and ICT literacy it is less clear to what extent they covary with each other, ICT literacy is a precursor of APS, or to what extent they are the same construct.

3.2 Cognitive precursors of APS

In the previous section the important distinction between covariates and precursors of APS was made. There, basic numeracy and reading skills were identified as relevant precursors of APS, whereas literacy and numeracy were identified as covariates of APS. Other important precursors that impact and, to some extent, are preconditions of APS are associated with basic components of general cognition architecture constraints (McGrew, 2009). That is, people vary on many of these cognitive components, notably executive control, working memory capacity, monitoring of attention to relevant information, and speed and accuracy of perceptual-motor-cognitive operations (Baddeley, 2007; Demetriou, Mouyi and Spanoudis, 2008; John and Kieras, 1996; Wiley and Jarosz, 2012; Wüstenberg et al., 2015). Some of these cognitive constraints may systematically vary by age and culture (Suto and Kumada, 2010).

The cognitive processes mentioned here have one common feature: They all can be considered rather fundamental cognitive processes. Theoretically they are identified in so-called cognitive cascade models. These models assume that more complex cognitive processes (often labelled higher-order thinking skills such as APS) are built upon the foundation of more fundamental cognitive processes that are developed at an earlier age. In this, the examples of fundamental cognitive processes mentioned above are precursors in the sense of an understanding of cognition as an evolving cascade that are important in more complex cognitive activities starting in adolescence, including processes within APS. Most of these fundamental cognitive processes are not generally considered malleable (or at least very difficult to do so) and are expected to affect success in answering numeracy and literacy items as well as problem-solving tasks.

While these preconditions are of a very general nature and can be considered precursors of a number of skills (including APS, literacy, and numeracy), there are some cognitive processes considered more central to the construct of APS. These processes will be brought to bear during typical problem-solving activities. These include: (1) activating and using prior knowledge and metacognitive strategy knowledge;

and (2) general reasoning skills. Because they are conceptually relevant for the understanding of APS as put forward in Figure 2.1, both will be discussed in some more detail here.

The role of prior knowledge in problem solving

Two types of knowledge that can be brought to bear in problem solving are general knowledge and metacognitive strategy knowledge. General knowledge is knowledge specific to the meanings of objects and their relations to understand the situation and affordance of objects for solving the problem. It is closely related to crystallised intelligence (McGrew, 2009). That is, solving problems requires knowledge of and familiarity with the specific objects to be acted on as well as the methods for transforming those objects to move to the goal state, which, in turn, is closely related to the use of operators. These objects can include knowing about people or situations such as when buying a lamp, who sells it, attributes of lamps, and potential interactions for buying and selling objects. General knowledge will be required to some extent given that the problems will be based on those situations that adults would likely encounter in their work, social, or political life. Creating problem situations for the assessment in PIAAC with strong face validity and embedded in a short scenario will necessarily require some knowledge of the world the problems are embedded into, especially factual and conceptual knowledge, which is required for creating and updating a situation model for any problem scenario (Graesser and Clark, 1985; Kintsch, 1998; O'Brien, Cook and Lorch, 2015; Zwaan and Radvansky, 1998). This knowledge is likely to be most useful when it supports an understanding of the structure of a system or the problem, which forms a pre-requisite of successful action going beyond the mere surface features (Goode and Beckmann, 2010). This type of knowledge is therefore most important for representing the current state and the goal state and understanding potential intermediate states derivable from knowledge of possible operators.

A second type of knowledge, metacognitive strategy knowledge, is even more fundamental to the process of APS (Antonietti, Ignazi and Perego, 2000; Scherer and Tiemann, 2014; Wüstenberg et al., 2014). Problem solving requires the selection and implementation of operators and plans for transforming states. The solver has to, therefore, have knowledge of these operators and heuristics as well as their applications. This could also include knowledge of criteria for evaluating quality of problem solutions or one's epistemic beliefs, which may constrain operator selection (Bråten et al., 2011; Rapp and Braasch, 2014). In fact, metacognitive processes are considered a central part of APS as the entire process of problem solving heavily relies on the ability to monitor, change, and adapt according to both the internal world and the information environment. Along these lines, metacognitive strategy knowledge can be considered an important precursor of the type of meta-cognitive processes required in APS. Again, there may be systematic differences in knowledge based on culture (Güss and Wiley, 2007).

The role of reasoning in problem solving

Reasoning in its various facets involves extracting similarities and contiguities between objects, interpreting rules, making inferences, correctly ordering and sequencing items, and thinking in a logical way to form a conclusion or make a decision (Evans et al., 1999; Leighton and Sternberg, 2004; Sloman, 1996). Several of the cognitive and meta-cognitive processes in Figure 2.1 involve reasoning processes that are considered important in problem solving such as information search and retrieval, mental model integration, distinguishing features, evaluating alternatives and monitoring progress or comprehension. In fact, simple problem solving is often found as a major constituent of definitions of reasoning. Performance on measures of reasoning is generally found to be predictive of performance in problem solving (Bühner, Kröner and Ziegler, 2008; Gonzalez, Thomas and Vanyukov, 2005; Wittmann and Hattrup, 2004). Problem solving differs, however, from reasoning in important ways that are precisely targeted in APS such as the need to acquire additional information by engaging strategically with the environment and responding to impasses and unexpected events (Funke, 2001; Wüstenberg, Greiff and Funke, 2012). As problem solving often involves more steps and longer sequences of solution paths, metacognitive processes

such as consistent monitoring and evaluation are more often present in problem solving than in reasoning tasks. In a nutshell, reasoning can be considered one of the most relevant cognitive precursors of problem solving in general and of APS in particular.

3.3 Non-cognitive precursors of APS

Apart from cognitive processes such as reasoning and general knowledge, several volitional and motivational processes are central to the construct of problem solving and will generally be brought to bear during typical problem activities. In fact, some of them are essential in performing on any cognitive tasks. Although research directly identifying the role of volition and motivation in traditional problem-solving tasks has been limited and is virtually non-existent for those aspects of particular relevance in APS, there is a growing body of research showing their role in other complex tasks that involve higher-order thinking. Some of these non-cognitive factors are generally considered important across any challenging task including achievement motivation (Dweck and Leggett, 1988; Nicholls, 1984), beliefs about content (Eagly et al., 2000), beliefs about learning (Grant and Dweck, 2003), and expectancies for success (Nicholls, 1984). Others are more specific to APS such as problem solving self-concept that is likely to play a role in task performance. According to Figure 2.1, APS extends problem solving to include a larger role for executive control and metacognitive awareness of how to strategically co-ordinate plans and sub-goals - areas where there is great variability in self-regulation skills (Azevedo and Cromley, 2004; Graesser, McNamara and VanLehn, 2005; Greene and Azevedo, 2007; Winne and Hadwin, 1998). To this end, self-regulatory skills, which in turn show conceptual ties to metacognition, are likely to be of relevance in APS.

Several other non-cognitive factors such as personality attributes are considered relevant for APS. One’s adaptability to novelty, uncertainty, and change (Martin et al., 2012; Martin, et al., 2013), intellectual curiosity (Grossnickle, 2016), and general anxiety or stress associated with novelty, uncertainty, impasses, and even computers and testing (Sommer and Arendasy, 2015) can affect problem solving and some of them even more so APS considering the specific setting in which APS is embedded. Further, one’s willingness to engage, as measurable for instance through perseverance and openness, has been found to correlate with successful problem solving in some empirical studies (LePine, Colquitt, and Erez, 2000; Lakhani et al., 2007; Scherer and Gustafsson, 2015). Given the positive correlation between time-on-task and a successful outcome for problem solving in technology-rich environments as captured in the first cycle of PIAAC (Rouet, Vörös and von Davier, 2014), it may be that some test-takers did not really “fail” the task but rather did not even attempt to solve it. Methods of improving willingness to engage may be important as well as perseverance in working on tasks. Finally, there is a growing body of literature with school age participants, but not yet applied to adults, that one’s self-concept of problem solving will affect one’s problem solving demonstrated in an assessment (Meißner et al., 2016; Tornare, Czajkowski and Pons, 2015).

SECTION 4: SOME OVERARCHING ASSESSMENT PRINCIPLES RELEVANT FOR THE ASSESSMENT OF APS

The most general notion that should inform the task development in the second cycle of PIAAC is that the conceptual framework should be directly represented in the tasks; both at the level of the overall definition of APS and at the level of the assumed underlying cognitive and meta-cognitive processes (see Figure 2.1). Put differently, the assessment tasks must, as comprehensively as possible, represent the dimensions of the conceptual framework. This means that different tasks should not only have different requirements regarding the underlying processes that they involve, and the level of difficulty they entail, but also, and equally importantly, that the overall collection of tasks should fully cover the construct of APS. On a more specific level, and in light of the experience gained from previous problem-solving assessments in international large-scale studies, it is critical that the APS assessment tasks reflect all the core elements of the construct. This includes cognitive and meta-cognitive processes, the nature of problems, and potential assessment contexts. Special attention should also be paid to the authenticity and cultural fairness of the APS assessments.

The APS assessment should cover the following distinct aspects of adaptive problem solving:

- ***Assessment of competence in problem solving:*** This may involve, for example, an accurate derivation of mental models that capture the problems, goals, plans, and resources to achieve solutions in everyday life.

- ***Assessment of performance during potential solutions:*** For example, this includes measuring alternative methods to solve the problem, task completion times, and number of errors.

- ***Assessment of situations in which particular problem-solving activities and adaptability should be initiated:*** This involves identifying situational patterns that trigger or enable problem-solving plans. It also depends on the cognitive availability of relevant information and the subjective estimate of costs for reaching goals through alternative solutions. This includes the ability to adjust goals, strategies, and mental models to new or changing information throughout the problem-solving process. Meta-cognitive knowledge and skills as well as self-regulation are essential for this aspect (e.g. Thillmann et al., 2013).

Given the complex and multifaceted character of APS as laid out in Figure 2.1 and time constraints during test administration, the assessment can only represent a restricted rather than exhaustive range of problem situations that can be encountered. The PIAAC Expert Group on Problem Solving considers problems in the contexts of social communication, planning, and information retrieval to be the most relevant for the APS assessment in the second cycle of PIAAC, given the target population and the broad aims of the study. Nevertheless, as these contexts and the corresponding assessment tasks will not cover the entire problem space, analyses and inferences should clearly state that such focus would mainly reflect people's ability to solve problems that require an interaction between the problem solver and the physical, social, and digital information environment. The interactivity can be implemented in computer-based assessments (Guthrie et al., 2015; Scherer and Tiemann, 2014), which allow problem solvers to actively engage in search and application processes that require the identification of relevant information from multiple sources and responses to feedback from the environment. Moreover, computer-based assessments

provide opportunities for administering tasks that present novel information or changes during the problem-solving process such that adaptability is required (Scherer, 2015a).

Below, a number of assessment principles are outlined, which may help in order to achieve an as-close-as-possible connection between the conceptual and assessment frameworks and, thus, an optimal construct representation in the assessment instruments.

4.1 Coverage of problem-solving processes

Regarding the assessment of cognitive processes involved in APS (see Figure 2.1), ideally, each item within a task or stimulus should refer mainly to a single cognitive process; yet, this may be difficult to achieve in practice because many cognitive processes of problem solving such as searching for potential operators and identifying problem solving strategies require an understanding and definition of the problem. This, in turn, makes it crucial to carefully define which cognitive processes actually are assumed to be involved when working on a specific task.

Even more challenging is the assessment of meta-cognitive processes involved in APS (see Figure 2.1). Regarding their assessment, a number of indicators can be developed on the basis of the following data sources: (a) responses to explicit questions about meta-cognitive knowledge by, for instance, evaluating alternative solution paths (i.e. procedural knowledge about problem-solving strategies) or reflections on the chosen solution or alternative solutions; (b) reactions to novel or changing information/situations that require changes in goals or strategies in the course of solving a problem (e.g. by observed adaptations of strategies or mental models); (c) adaptations of problem solutions as a result of monitoring and reflection of a given solution; (d) the sequence of problem-solving steps or more fine-grained actions. Specifically, the changes in the frequencies of applying specific strategies such as the vary-one-thing-at-a-time strategy (VOTAT) across a number of different problem-solving tasks in which other strategies might also be constructive may serve as a potential indicator of meta-cognitive regulation and the degree to which problem solvers can adapt to novel situations. It is important to note that the APS tasks and the resulting data put in front the processes of problem solving, such as the adaptation of strategies in order to solve problems that are dynamic and changing in different contexts. The expert group believes that this focus on the problem-solving processes might improve the cross-country comparability of the APS assessment and the derived measures.

These assessment principles specifically imply that convergent and discriminant validity needs to be established at the conceptual level. For instance, for any item within a task (i.e. unit), it must become clear which of the assumed APS processes are mainly covered (convergent validity). Besides, discriminant validity is essential. For example, reasoning is involved in problem solving and adaptive behaviour (Mayer, 2014; Wirth and Klieme, 2003; Wüstenberg, Greiff and Funke, 2012); hence, it needs to be clarified which particular role reasoning plays for APS performance (see Section 3 on precursors of APS).

4.2 The nature of the problems

Some problems are static in the sense that the given states and the goal states are clearly identified up front, and the states do not change throughout the course of the problem. Moreover, all information necessary to solve the problem is given at the outset of the problem-solving process (Leutner et al., 2012). Other problems are interactive in the sense that the social and/or physical world presents information that is novel to the problem solver, and the information needed in order to solve the problem is not immediately obvious (Funke, 2010). As a consequence, problem solvers need to interact with the external world and information environment in order to obtain information about the problem, its defining variables, and their relations (Greiff et al., 2013). This new knowledge can subsequently be applied in order to search for strategies and operators and to apply them in order to find a solution. In dynamic problem situations, initial

states, goal states, variables and their relations, or even problem goals may change in the course of the problem-solving process. Dynamic problem situations require adaptability (Osman, 2010; Scherer, 2015a; VandenBos, 2007). Many real-life problems are interactive and dynamic and can be characterised as information-rich (Rouet, Vörös and Von Davier, 2016): solving these problems requires individuals to access, evaluate and use information. For instance, navigating through webpages that are unfamiliar to the problem solver and selecting information that is relevant for the task are skills needed to solve information-rich problems (OECD, 2013b, p. 121).

An additional problem type is called analogous problems. Analogous problems are problems that require problem solvers to transfer a problem-solving strategy used to solve in a particular problem to a different, but similar problem. These problem types may inform the development of problem-solving tasks that tap the previously described cognitive and meta-cognitive processes (Figure 2.1) and, at the same time, allow for the administration of tasks that require adaptability. Given that APS involves adaptive behaviour in novel and changing situations, the assessment should be computer-based allowing for dynamic and interactive problem types. In order to implement these problems, simulations and micro-worlds may be used to represent key aspects of the external world (Bennett, 2015; Greiff and Wüstenberg, 2014). The PIAAC problem solving experts group recommends to include interactive, dynamic, and information-rich problems and to complement some problems with analogous problems.

4.3 Reliance on reading literacy, numeracy and prior knowledge

To minimise the level of literacy required, stimulus material (and task statements) should be as clear, simple and brief as possible, except when the complexity of the materials is construct-relevant (e.g. amount of distracting information for information-rich problems). In previous assessments of problem solving, animations, pictures or diagrams have been used to balance the demands between verbal and other information-processing skills. Numeracy demands have also been kept to a minimum with, for example, running totals provided where appropriate (OECD, 2012). At the same time, literacy and numeracy form precursors of APS to a certain extent (see Section 3) in that the former is needed to understand and solve the tasks, and therefore can be considered to be part of the tasks, whereas the latter will not be part of the APS tasks. Along similar lines, although prior knowledge should be required to some extent for successfully solving the problems, keeping these requirements low would be beneficial for the PIAAC APS assessment. In other words, the majority of APS tasks should require only little prior knowledge, but rely heavily on underlying problem-solving processes. It is an overarching principle of the APS assessment to be interactive in a sense that the information needed to solve the problems can be acquired during the problem-solving process (e.g. by providing access to multiple information resources or knowledge systems). At the same time, potential interferences with prior knowledge are acknowledged (see Section 3).

4.4 Problem contexts

Potential contexts may comprise personal, work-related/occupational, and civic/social problems. These problems may present problem solvers with situations in the areas of social communication, information retrieval based on large amounts of data, or planning, and require the use of digital technologies. In this sense, digital technologies serve both as a medium in order to solve problems (e.g. planning a trip with multiple stops and stay overs) and as a context that provides problem situations (e.g. trouble-shooting problems, problems caused by the use of digital technologies). In this, the expert group acknowledges that the selection of contexts will necessarily limit the breadth of the APS assessment given time constraints for the assessment. To mitigate this concern to the largest extent possible, the group advises the team that will be responsible for developing assessment tasks to review contexts that are relevant and feasible for developing assessments tasks, and to make informed choices such that a variety of contexts are covered. Nonetheless, although little prior knowledge about the problem contexts might be required, context independence of item responses or response strategies cannot be fully ruled out. It is

therefore important to examine potential dependencies from a conceptual and empirical perspective. As noted earlier, the expert group emphasises that PIAAC 2 will primarily focus on the processes of APS across a number of contexts and not so much on the specific content. These processes are, at least to some degree, generic (Greiff et al., 2014). Put in other words, although the contexts of the APS tasks differ, the strategies and processes that are required to solve them are comparable. In this respect, the expert group expects the APS assessment to be invariant across different contexts to a substantial degree. It is likely that this invariance might also improve measurement invariance across the participating countries.

4.5 Relations between PIAAC 1 and PIAAC 2

It is important to note that the core construct APS – as it comprises cognitive and meta-cognitive processes that come into play when solving dynamic, changing, and novel problems – deviates from the PIAAC 1 conceptualisation of problem solving (cf. also Table 2.1). Whereas PIAAC 1 focused on solving information problems with the help of technology-based tools and information resources, PIAAC 2 focuses on an adaptive component in the assessment. This component is reflected in the design of the tasks, such that problem solvers are required to perform adaptive behaviour in given situations.

In light of the conceptual framework of APS and its deviations from that presented in PIAAC 1 (see Section 2), the assessment of APS in PIAAC 2 should contain a large number of newly developed tasks. These tasks should be closely connected to the conceptual framework proposed in this paper in order to capture as many facets of APS as possible. This, however, might compromise the link to the PIAAC 1 assessment substantially. In fact, the decision to focus on a new construct or form of problem solving in PIAAC 2 provides only limited opportunities to examine trend over time given that the available assessment time is limited. In order for the PIAAC 2 study to appropriately assess APS as a new construct, a sufficiently large number of items representing this construct are needed. The expert group is aware of the need for balancing two priorities for PIAAC 2: (1) Examining APS as a new construct with a new assessment; and (2) linking the problem-solving assessments in PIAAC 1 and PIAAC 2 such that trend analyses are possible. Given the critical relevance of APS in our society as outlined in this paper, the expert group recommends prioritising the development of a new assessment domain rather over maintaining trends. Constraints on respondents' time mean that it is operationally not possible to maintain trends for PS-TRE while expanding the assessment to effectively cover APS. Nonetheless, the group believes that the possibility of developing additional (small-scale) empirical studies to identify how the PIAAC 1 PS-TRE and the final PIAAC 2 problem solving assessment are related should be conducted.

4.6 Design of stimuli

Generally, the stimuli of problems and the corresponding interface should be intuitive, and solutions to problems should by no means require familiarity with a specific interface. A scenario-based assessment is preferable, because scenarios could be presented in visual format to reduce literacy requirements (if possible). A scenario-based approach is also recommended on the basis of the benefits of anchored instruction and assessments (Choi and Hannafin, 1995; Cumming and Maxwell, 1999; Herrington, Reeves and Oliver, 2014).

Instructions should relate to real-life problems embedded in semantic contexts that tap the physical, social and digital information environment (Figure 2.1). The stimuli themselves convey meanings, whether they are presented in the form of words, static, or dynamic pictures or anything else. In addition, in real life there does not seem to be any context-independent or knowledge-free problem solving. This raises the issue of how familiar or unfamiliar the scenarios are offered as part of the assessment. Although there seems to be consensus about the fact that most if not all tasks should be to at least some extent familiar, some controlled variation of familiarity or novelty may provide helpful information to understand problem-solving proficiency. Such a variation should be carefully checked against any potential cultural bias, that

is, less familiar problems should be equally less familiar to participants independent from their country and cultural milieu.

In addition to this, some of the problems should be solvable not only by giving one specific answer, but by allowing participants to get to the solution by using multiple paths or providing alternative solutions. That is, the problem space (i.e. the family of solution paths to achieve a goal in a specific problem) and the flexibility participants have to move through the tasks should be substantial and an integral part of item development. As a consequence, there would be a discrete objectively correct answer so standard psychometric methods could be applied for some items. However, for other items there would be a continuous measure that, for example, reflects the time participants spent until solving the task, the effectiveness of their navigation path (e.g. during the search processes; see Figure 2.1), and positive (versus negative) score points per time unit or per N actions.

As mentioned earlier (Section 2, see Figure 2.1), for a problem to demand adaptability, the stimuli should be designed in a way that dynamic changes of the problem situation, information resources, or the relevant goals are possible. This might be accomplished by providing the problem solver with problems that include multiple goals that need to be dissected in relevant sub-goals ("Setting sub-goals"; Figure 2.1), multiple solution steps that cover the definition of the problem, as well as search and application processes, and/or dynamic changes that may require adjustments of goals or strategies ("Changing goals and strategies").

In order to cover a broad spectrum of performance, tasks and items of varying degrees of difficulty are preferable. These tasks/items can be systematically varied in their complexity; yet, complexity and the potential drivers for items difficulty are still to be identified. Drawing on some experience obtained from the PISA 2012 problem-solving assessment, a number of drivers could be taken into account (OECD, 2013c, p. 129): Amount of information, representation of information, internal complexity, distance to goal, multiple goals or tasks – just to name a few.

4.7 Psychometric considerations

Generally, under ideal circumstances, the assessment should cover a large number of items that involve short response times per item. However, as a complex skill, APS requires more thought; this, in turn, may require longer stretches of time. For instance, the processes of defining the problem (e.g. "Selecting, organising, and integrating problem information into mental models"; see Figure 2.1), the immanent monitoring of the extent to which the understanding of the problem situation is accurate ("Meta-cognitive processes"), and necessary adjustments of goals and strategies during the search processes are not necessarily automated processes and may therefore require more time (e.g. Goldhammer et al., 2014). A consequence of this challenge is that, compared to other assessment domains, there will be fewer problem-solving tasks and contents, with several items per context (i.e. task or unit). Implementation of bundled items is that they may tap into similar constructs or entail contextual dependencies, which might increase collinearity. As a consequence, a compromise might be to ensure that the items included within each scenario relate to a broad diversity of problem solving processes. Controlled variation in the presentation order of items within scenarios may also be considered.

More specifically, strict dependencies between tasks and/or items must be avoided, and a sufficient number of tasks and items within tasks need to be administered. That is, large and extensive problem sets with substantial item dependencies and psychometric issues should be avoided, because they may not only limit the representation of the construct (Wilson, 2009) but may also cause severe problems in establishing a problem-solving scale (Scherer, 2015b). Hence, it is desired to administer a number of clearly defined problem sets (systems) with varying degrees of complexity/difficulty helps us to gather as much information on participants' adaptive problem-solving skills in a reasonable time (Greiff and Martin,

2014). Specifically, problem-solving scenarios comprising multiple problems can be posed regarding the same context ("nested item design") – otherwise participants will have to invest too much time to understand the problem context and this may limit the number of items that can be administered considerably.

Given that PIAAC aims at assessing APS with computer-based tests, different kinds of log file data can be used to describe problem-solving processes. Specifically, the resulting data may comprise:

- *Responses* to problem solving items, which can be scored according to their correctness – Item responses are used to form the problem-solving scale, a scale that represents participants' performance.

- *Response times* for single items or multiple-item tasks – Response times may serve as indicators of test-taking engagement (Goldhammer et al., 2016) or problem-solving speed, a cognitive trait associated with the accuracy of item responses (Klein Entink et al., 2009; Scherer, Greiff and Hautamäki, 2015). Moreover, response times may inform test development in that the feasibility with respect to the time-on task can be examined (Goldhammer et al., 2014).

- *Behavioural data* (e.g. number and sequence of actions/steps, divergent problem solving paths, use of information material, adaptability of solution strategies) – these data provide specific information on participants' strategies to solve problems (e.g. control-of-variables strategy; Greiff et al., 2016; Tschirgi, 1980) and the consistencies or changes thereof (Scherer, 2015a). Moreover, the relation between the use of specific strategies and performance can be examined (Vörös and Rouet, 2016).

- These log file data have the potential of providing further insights into: (a) the processes and strategies of APS; and (b) the functioning of the specific APS tasks. Both aspects contribute to establishing a validity argument for the proposed assessment (Pellegrino, DiBello and Goldman, 2016). In particular, with respect to: (a) log file data comprise information on the sequence and duration of actions, and the actions themselves. In order to make use of these information sources, the first challenge that needs to be addressed lies in the transformation of raw log file data into more structured and accessible data. Whereas some researchers acknowledge the complexity of this transformative process (Mills and Breithaupt, 2016), others have demonstrated its feasibility if a-priori assumptions on the problem solving strategies that might occur exist, even in large-scale, educational data sets such as PISA 2012 (Greiff, Wüstenberg and Avvisati, 2015) and PIAAC 1 (Goldhammer et al., 2016). At this point, the expert group notes that the specificities of the data transformation process need to be addressed at a later stage during the test development process. Nonetheless, the group emphasises that the process indicators derived from log file data need to be developed on the basis of theoretical assumptions during the item development. These indicators can be further extended on the basis of empirical analyses.

Although a considerable number of process indicators – indicators that describe aspects of the problem-solving processes in the APS tasks – can be developed in the phase of item development, the expert group believes that the Vary-One-Thing-At-a-Time (VOTAT) strategy is a good example of the kind of information that is likely to come out of log-file analyses This strategy points to the heart of problem-solving processes in situations where knowledge about a system of variables does not exist a-priori (Greiff et al., 2016). In fact, this strategy is in some problem situations the most efficient in order to generate knowledge about how variables are related. Proficient problem solvers apply this strategy to develop mental models about how an unknown system of variables works (Greiff et al., 2015). The value of this strategy has therefore been acknowledged in various domains (e.g. Schwichow et al., 2016). In this respect, log file data provide information about how problem solvers manipulate variables within, for

instance, a simulation of a technical device (e.g. a remote control) and such definition and subsequent explication of strategies could be applied for a range of different tasks in PIAAC as well building upon and extending beyond the VOTAT work. Examining the sequence of actions and how variables are manipulated in log files, analysts are able to keep track of strategy use and change across tasks and over time (Greiff et al., 2016; Vollmeyer, Burns and Holyoak, 1996). Hence, even adaptations of strategies when tasks change can be investigated.

With respect to (b), log file data contain information that may inform item developers about the feasibility of specific items. For instance, response time data inform the process of test assembly and may be used as indicators of test-taking engagement (Goldhammer et al., 2016). In addition, traced actions during test-taking might reveal the extent to which problem solvers make use of specific material provided in order to solve a given problem (e.g. help functions, links to hypertexts). This information contributes to refining items in order to achieve an optimal test design in PIAAC 2.

Overall, the expert group believes that examining log file data in PIAAC 2 provides valuable insights into the processes of APS and the nature of tasks. This builds on the fact that log file data have been successfully employed in the past, also in large-scale data sets and for a number of reasons, among them identification of strategic behaviour. However, the best results will be achieved when the conceptual work on log-file indicators is done during the process of actual item development.

4.8 Relations to ICT skills

Although it is desired to develop tasks that require only limited ICT skills in PIAAC, precisely how APS will be differentiated from ICT-related and other skills such as collaboration will be an ongoing debate during the development of the assessment. For example, a competent problem solver will need to make judgments on whether to rely on a computer facility, other people, and their own individual problem-solving capacities to handle problems they encounter. This decision taps different channels and resources through which problem solving takes place. At the same time, it also emphasises the role of ICT as a means to solve problems in the 21st century, which are in fact most often solved by using ICT. Hence, knowledge of ICT, or other people, are likely to guide the text-taker's decisions in problem-solving activities. Overall, the reliance on ICT could become an explicit dimension in the assessment framework. This topic will be discussed in-depth later in this paper (see Section 6).

SECTION 5: GETTING AN IDEA OF THE ASSESSMENT BY IDENTIFYING TASK EXAMPLES

The PIAAC assessment of adaptive problem solving contains scenario-based tasks, which describe everyday and working-life problems. These scenarios are relevant for all age groups to a similar extent. It is desired to design problems with universal contexts, which are relevant in all participating countries (see Section 4). Along these lines, the problem-solving tasks should reflect a broad spectrum of problems that people face in the 21st century (see Section 1) and the definition of problem solving in Section 2. Moreover, variation in difficulty and complexity is desired, particularly easy items that can involve an explicitly stated goal in a single familiar environment with few actions are considered important also with respect to potential non-ICT versions of the tasks (Section 6). In fact, some of the problems should be information-rich and involve multiple tasks that are distributed over time and subject to constraints of the external world.

5.1 Specific suggestions on contexts and tasks

As mentioned earlier (see Section 4), the PIAAC assessment of adaptive problem solving may cover personal, work-related/occupational, and civic/social contexts. These contexts may relate to social communication, information retrieval on the basis of large and/or conflicting amounts of information, and complex scheduling/planning tasks. The following problem situations might provide examples for such tasks:

- Planning travel/holidays with different family members having different preferences and with a limited budget.
- Renovating an apartment with multiple tasks that depend on each other and that may change due to unforeseen obstacles (order of tasks important).
- Selecting a product that needs to satisfy a number of constraints (e.g. a cell phone from a selection of cell phones with different features or a photo book).
- Scheduling a work-related meeting by considering multiple time constraints from colleagues and adjusting the schedule due to changes in individuals' schedules.
- Searching for information on a specific topic and choosing among multiple information sources (e.g. information needed to help kids with their homework on the WWW, or in books).
- Taking care of a sick child (e.g. monitoring health changes, ensuring that medicine is administered with the correct dosage, deciding on what to do based on information in an article).

Three sample tasks are outlined below.

Box 5.1 Example task 1

Planning a day under multiple constraints and with multiple goals

Task description: A person needs to accomplish multiple goals in the course of a day. These might involve: (a) preparing a dinner with fish (perishable if not refrigerated for more than 4 hours) to be served at 7pm; (b) picking up a child from school at 3pm; (c) replacing or repairing a broken chair to be used at the dinner table. Participants would need to plan and enact the day to accomplish these goals. In order to increase the complexity of this problem, there could be different constraints that may or may not occur suddenly: Multiple markets/stores would be positioned at different locations, the vehicle could have a limited amount of fuel, and the person could have a limited amount of money, and so on. The person would encounter unexpected obstacles and require re-planning (e.g. the closest market is out of fish, the student needs to stay an extra hour at school), or would encounter unexpected opportunities (e.g. the chair or a tool to fix the chair is on sale at the fish market, the fish can be preserved on ice in a container in the vehicle). Performance is measured by the number of goals accomplished, successful prospective memory (getting to the school on time) and successful uptake of opportunities (purchasing the chair/tool at the fish market), speed of accomplishment, amount of money spent, distance travelled, and so on.

Problem context: Personal.

Problem-solving processes: This problem task may require enacting almost all processes proposed in the APS conceptual model (Figure 2.1). For instance, in order to plan a day, the goals that need to be accomplished must be identified ("setting goals"). Subsequently, information can be gathered that describes the different constraints such as timing or dietary requests ("searching for information"). This information needs to be structured according to the identified goals by making a list of fixed appointments; this process can be visualised in some kind of day planner, be it in paper-and-pencil or computer-based form (e.g. using a calendar app) ("selecting, organising, and integrating problem information"). During the searching phase, a detailed plan for the day is developed on the basis of the previously identified goals and information about the "environment"; the latter refers to information about traffic, public transportation, other, interfering meetings at work, etc. Once different options of how to organise the day have been evaluated (evaluating alternatives"), a final plan can be developed ("applying plans to solve problems"). This description of the cognitive and meta-cognitive processes is by no means exhaustive.

Role of ICT: This problem task can be solved even without drawing on digital tools, information, or resources.

Box 5.2 Example task 2

Update of a smartphone app

Task description: A simulation is provided on screen that displays a social communication app in a smartphone. Similar to the assessment of complex problem solving in micro-worlds (Greiff et al., 2016), problem solvers are asked to find out the functionality of this app by systematically interacting with the underlying system. Specifically, different functionalities can be explored that enable users to connect the app to an existing address list, set up a user account, form communication groups, or use the chat option. In the subsequent task, a specific problem is given, in which a communication group (e.g. with the interest of planning a birthday party and making sure that the person whose birthday will be celebrated is not included) must be formed in order to initiate the planning. During the planning, an unexpected software update is performed, which leads to changes in the functionalities of the communication app. The planning must go on, and problem solvers need to adapt to these changes.

Problem context: Personal.

Problem-solving processes: This problem task may require enacting almost all processes proposed in the APS conceptual model (Figure 2.1). Of special interest is the extent to which problem solvers react to the changes encountered within the micro-world. For instance, once the update has been completed and users want to perform the tasks they used to perform on their smartphone, users' need to adjust their mental model about the smartphone functionalities; this requires the performance of definition and search processes such as "selecting, organising, and integrating information" and "evaluating the quality of information". In some cases, the change in functionalities may also require an adjustment of strategies and procedures, that is, actions to achieve a goal such as writing an email. In other words, users may need to perform different actions than they were used to ("changing goals and strategies"). In order to adjust these actions, appropriate operators are chosen and alternative actions are evaluated ("choosing operators", "evaluating alternatives").

Role of ICT: This task focuses heavily on ICT; it uses ICT as a context (i.e. software update in a smartphone) but also as a tool (for planning the birthday party). The process of acquiring knowledge about the problem can only be accomplished by interacting with the digital environment.

Box 5.3 Example task 3

Reflect on a solution and/or the solution process

Task description: In order to assess adaptive problem solving more broadly, further questions could be considered that go beyond asking participants to merely solve problems that are comparable to those presented above. Potential items may be:

a. Is the information given sufficient to solve the problem?
b. Which information is required to solve the problem?
c. In situation X the solution was Y. Could you use Y also in the present situation? Why (not)? How would you have to modify Y?
d. Which of the given problem solutions could be applied best to solve the current problem?
e. Person A has solved the problem in a particular way (a description of the solution and the solution process is provided). Is this a good solution? Why or why not?

Problem context: Depends on the context specified in the actual problem task.

Problem-solving processes: These questions require participants to reflect on both problem solutions and the solution process, and therefore tap meta-cognitive and self-regulatory aspects of adaptive problem solving. For instance, in order to decide on the best solution to a given problem, search processes such as “evaluating alternatives” and processes that belong to the “application” dimension (e.g. “reflecting”) need to be performed. In particular, when evaluating a set of given solutions, problem solvers have to evaluate the extent to which these solutions meet the previously identified demands on a potential solution; hence, different meta-cognitive processes interact in this scenario (e.g. “monitoring comprehension”, “evaluating alternatives”, and “reflection”).

Role of ICT: Depends on the context specified in the actual problem task. Some of these items may require accessing or retrieving additional information and/or testing alternative solutions with the help of a digital device.

SECTION 6: THE RELATIONSHIP BETWEEN ICT LITERACY AND ADAPTIVE PROBLEM SOLVING

The spread of information and communication technology (ICT) has raised an interest for the new skills people need to possess in order to function effectively in the digitalised society of the 21st century, whether for education, work, or other purposes. As a consequence, several studies have been specifically devoted to students' experience of and ability to use ICT (OECD, 2006) and, more recently, to people's ability to solve problems in technology-rich environments (OECD's Survey of Adult Skills, i.e. the first PIAAC cycle; OECD, 2013a). People's experience with and ability to use ICT is captured in a number of expressions ranging from ICT familiarity to digital competence to ICT literacy (Ferrari, 2012; see below for a more detailed discussion). For purposes of consistency, the latter phrase is used to designate people's knowledge of and experience with ICT. Regardless of the precise definition applied, ICT literacy overlaps with adaptive problem solving (APS) in that most ICT uses involve non-trivial actions and operations (see above, Section 2), and a high level of interaction and opportunism.

Generally speaking, the relation between ICT and APS is complex for at least two reasons: First, ICT itself, as a set of emergent technologies, has been changing constantly over the past decades, with new devices and services appearing every semester, whereas others fade away after just a few months in use. Second, the availability of ICT is changing the way people solve problems in many, although not all, areas. More specifically, the OECD's Survey of Adult Skills (OECD, 2012) has identified three ways in which technology may change problem solving:

- People solve "old" problems differently because of the new tools available (for instance, managing personal finances on a computer using a spreadsheet, as opposed to a notebook and a pocket calculator).

- People also solve "new" problems by themselves because of the availability of new technologies (for instance, seeking advice about a medical condition from the web vs. from an expert consultant).

- People sometimes have to solve problems about ICT. For instance, people may need to fix a settings problem, or learn how to use new functions of their Internet browser.

The pervasiveness and importance of ICT along these three lines for solving all sorts of problems has raised the question of whether problem-solving skills can be defined independently from ICT skills, or whether purposeful ICT use and naturalistic problem solving could be integrated as a single domain. Indeed, some current and rather broad definitions of ICT literacy range from competencies of dealing with digital information (i.e. accessing, retrieving, and evaluating digital information) to operational computer skills (Ferrari, 2013; Fraillon et al., 2014). Solving information-rich problems individually versus collaboratively is also considered to be a dimension of digital literacy (e.g. Care et al., 2015; Ferrari, 2013). Hence, there is conceptual overlap between the two concepts of APS as defined here and digital literacy in a more general sense.

Despite the relations between APS and digital literacy, there are some theoretical and empirical reasons to consider the two concepts as distinct (Greiff et al., 2014). Therefore, in this paper we take the

view that problem solving and proficiency at using ICT are to be assessed as distinct but complementary constructs. We briefly review current definitions of problem solving and ICT literacy, and we propose an approach to assessing both domains in the second cycle of PIAAC.

6.1 Definition and dimensions of problem solving

As stated in Section 2, APS can be defined as a set of cognitive processes that operate through interactions with the external environment with the purpose of reaching a non-trivial goal. Most current problem-solving frameworks acknowledge that problem solving involves a set of generic steps and processes such as problem finding, planning, enacting, evaluating and monitoring one's actions, as can also be seen in Figure 2.1. These processes can apply to a broad diversity of problems and problem-solving environments. Therefore, at a core theoretical level, a psychological theory of problem solving may be articulated without any reference to a particular type of technology.

At the same time, APS requires the individual to interact with the environment to an extent that is likely to be higher than only a couple of years ago. Problem solvers need to direct their attention, process information, and act upon their physical and social environment (see Section 2). In addition, most problem-solving environments include man-made artefacts, that is, objects, tools, devices and other kinds of technology. People solve problems by attending to and manipulating those artefacts. Therefore, expertise in problem solving develops together with greater familiarity with the problem-solving environment and the typical tools and technologies that can be found in it (on this issue see Sweller's 1998 "Environment Organising and Linking Principle"). This is true for well-defined, information-lean types of problems such as playing chess, but also for more ill-defined problems involving an open environment, such as selecting the best photography book for a friend from a range of web stores.

More specifically, the three core phases of APS as defined in Section 2 include references to the problem solver's interactions with their environment: Problem definition (phase 1) relies on the person's past experiences in solving similar types of problems, which obviously involves their experience of the problem-solving environment; the search for a solution (phase 2) involves selecting appropriate devices and tools; and applying the solution (phase 3) is mostly done through the manipulation of these devices and tools. Therefore, a contemporary assessment of problem solving has to pay close attention to what people know and do with their problem-solving environments, including digital devices and applications.

6.2 Definition and dimensions of ICT literacy

As mentioned above, over the past two decades, several definitions and frameworks have been proposed to capture the essence of ICT literacy. As part of the European Commission's report "Digital Competence in Practice: An Analysis of Frameworks", Ferrari (2012) proposed to distinguish ICT literacy from the broader construct of "digital competence". Ferrari defined ICT literacy as "the knowledge and skills needed to effectively use hardware and software components" (p. 17). However, other definitions of ICT literacy link the competent use of ICT to the contexts and goals for which ICT use is required. For instance, in their feasibility study for the PISA ICT Literacy Assessment, Lennon et al. (2003) defined ICT literacy as:

> "The interest, attitude and ability of individuals to appropriately use digital technology and communication tools to access, manage, integrate and evaluate information, construct new knowledge, and communicate with others in order to participate effectively in society."

The latter definition comes closer to Ferrari's construct of "digital competence", which is defined as:

> "the set of knowledge, skills, attitudes (thus, including abilities, strategies, values and awareness) that are required when using ICT and digital media to perform tasks; solve problems; communicate; manage information; collaborate; create and share content; and build knowledge effectively, efficiently, appropriately, critically, creatively, autonomously, flexibly, ethically, reflectively for work, leisure, participation, learning, socialising, consuming, and empowerment." (Ferrari, 2012, pp. 3-4)

An interesting feature of Ferrari's definition, which was also featured in the OECD's PISA study of ICT literacy, is the distinction between knowledge, skills, and attitudes. Clearly, being ICT literate involves some declarative knowledge of the devices and applications; however ICT literacy also involves an ability to use ICT in efficient and effective ways, that is, a more procedural form of knowledge. Finally, the development of ICT literacy can be fostered or hindered by people's attitudes towards computers (e.g. computer anxiety; Powell, 2013).

6.3 Comparing and contrasting ICT literacy and problem solving

Several common points and differences emerge from this brief discussion of problem solving and ICT literacy (Table 6.1): ICT literacy is about the purposeful use of hardware and software artefacts and does not go beyond this, whereas problem solving can involve any kind of artefact (and sometimes even no artefact at all). ICT literacy is needed in a wide range of situations, including those that would not be described as problems (performing routine tasks). In contrast, problem solving involves non-trivial goals. ICT literacy is built through exposure to and experience with digital artefacts. This, in turn, raises the issue of whether people have access and opportunities to use ICT. Access and opportunities obviously depends on economic development and status at the country and individual level. In contrast, problem-solving skills may develop as an outcome of exposure to and experience with problems, as well as other dimensions whose relationship with economic status is more ambiguous.

Table 6.1 Comparing and contrasting ICT literacy and problem-solving skills

	ICT literacy	Problem-solving skills
Types of devices	By definition, ICT literacy is about the use of digital devices.	Some, but not all, adaptive problem-solving activities involve the use of ICT. Problem solvers may opt for solutions that involve the use of other resources (e.g. asks a friend).
Types of situations	ICT use can serve a wide range of goals, including but not limited to solving problems. Routine ICT uses may involve rather trivial situations. In terms of adaptive problem solving, some ICT uses do not involve the search for a solution and therefore they do not qualify as problems (Section 2).	By definition problem solving involves reaching non-trivial goals. There is always a need to search for a solution and to apply and monitor the effectiveness of the solution.
Relation to economic and educational dimensions	ICT literacy depends on one's exposure to and experience with digital artifacts. These may vary with the economic status of one's environment.	Adaptive problem solving is acquired through exposure and experience with a range of problems. Although an effect of education is to be expected, the connection with economic status is less clear.

6.4 Specific strategies for disentangling ICT literacy from the assessment of problem solving

Problems can vary on ICT knowledge requirements or complexity. For example, a web interface can be emulated by a set of options on the screen to press, much like many appliances (e.g. microwave). Donald Norman's (1998) visionary notion of invisible computers illustrates how people interact with artefacts in the world and do not even know they are computers. For instance, cars and washing machines have computer chips but the user does not feel they are using computers when they push the brake pedal or select a washing cycle. Skills of retrieving/locating information, comparing alternatives, and communicating information can be assessed with interface facilities that vary in digital complexity. Similarly, the presentation of options and visual depictions of information can vary in digital complexity.

Three possible and mutually compatible strategies may be pursued in order to disentangle the demands technology-rich environments put on the test-takers with respect to their digital literacy as opposed to the actual demands of the APS tasks:

- Design a companion ICT literacy assessment with a separate proficiency scale so as to be able to study the links between the two scales. The ICT literacy assessment could also be used as a screening procedure in order to check whether the person can take a computer-based assessment of APS, or even in general.

- Make technology requirements a dimension of the assessment of problem solving and vary the degree of ICT-related task demands. Some tasks should be more "technology-lean" than others, so that even people who have no or little digital literacy may have a chance to solve them. Other tasks would rely more explicitly on the use of ICT devices and applications (for instance, a web browser). A suggestion would be to generate items that require similar cognitive problem-solving processes (parallel items) but differ only to the extent to which they require ICT skills (e.g. additional requirement to search Internet for solution-relevant information, use digital tools to generate or communicate a solution).

- Assess the test-takers' prior experience with and uses of ICT as part of their personal and professional life in order to examine the relation between ICT experience and problem-solving skills. This could be done, for instance, by adding appropriate items to the background questionnaire (see Section 7).

One important question is how the second cycle of PIAAC could implement strategies to disentangle and investigate the relationships between ICT literacy and APS. However, an equally important and highly practical question is whether and how participants who have low levels of ICT literacy can be assessed with regard to APS because APS tasks are supposed to be delivered through technology-based assessment modes. Specifically, the expert group notes that the nature of APS (see Figure 2.1) requires tasks that rely on dynamic changes and rather complex stimuli (see also the task examples in Section 5), which are best implemented through some type of technology-based assessment. It is, thus, an open question whether at least some of the APS tasks can be developed in a way that they could also be administered on paper-and-pencil for those participants who cannot take the standard APS assessment.

The expert group is aware of this issue and encourages the main contractor to thoroughly work on this topic as the preparations for the 2nd cycle of PIAAC proceed. The group tentatively suggests a two-step strategy:

Step 1:

The percentage of participants who cannot take the standard technology-based APS assessment should be kept to an absolute minimum. Thus, the APS tasks should be developed in a way that their interfaces are easily accessible also for people with little experience with technological devices. One strategy might also be to use a technology for test delivery that minimises the need for prior knowledge and experience, for instance, by using tablets as the mode of delivery instead of computers.

Step 2:

Obviously, some participants will not feel comfortable or will be, for other reasons, unable to do any type of technology-based assessment no matter the level of accessibility of the devices and the interface. For those participants, it should be evaluated whether some of the APS tasks can be paralleled in a paper-pencil version so as to provide a somewhat restricted (in terms of item pool) but equally valid assessment of APS. The expert group would like to point out that at this stage it is difficult to evaluate final feasibility of such an approach, but the group is rather optimistic given that some kind of dynamic change in task constraints could be implemented in a paper-and-pencil format as well allowing for a sufficiently valid implementation of the principle of APS. Example task 1 in Section 5 gives an example of a task that could possibly be implemented without the use of technology. However, not all APS tasks can be implemented in this way and it is likely that those tasks for which it will be possible are located at the lower spectrum of task difficulty.

Thus, the expert group tentatively, and based on theoretical considerations, assumes that some type of non-technological assessment of APS might be feasible but likely only for the lower spectrum of APS skills, as it is not clear whether there will be adequate tasks for participants with low ICT literacy but high levels of APS skills (it is also not clear how large this group will be). It will be the task of the main contractor to explore potential solutions in-depth.

In summary, we have argued that ICT literacy and APS are two distinct but related constructs. ICT is part of many, but not all APS situations. Often, ICT is needed to use appropriate digital channels for the process of APS. In addition, some uses of ICT do not qualify as problems in that they involve familiar, immediately available goals and procedures. Due to the growing importance of ICT in everyday life, we have argued for the need to assess both ICT literacy and problem-solving skills in the second cycle of PIAAC. We have suggested several means on how this goal could be achieved.

SECTION 7: CONSIDERATIONS ON THE PIAAC BACKGROUND QUESTIONNAIRE

As laid out in the previous sections of this paper, APS is in itself composed of various sub-processes that are located both at the cognitive and the metacognitive level. In addition to this, APS co-varies with a number of other skills, most notably literacy and numeracy, and depends to varying levels on other cognitive and non-cognitive skills and individual circumstances.

The PIAAC background questionnaire (BQ) can serve the unique function of helping policy makers and researchers identify factors and conditions that promote proficiency in problem solving as well as the benefits that proficiency in problem solving has for success in the labour market and for individual well-being. Thus, the BQ serves the overarching purpose of gathering insights on various levels to the extent possible. A carefully designed BQ can considerably widen the understanding of the nature of APS. In fact, previous large-scale assessments have repeatedly shown the value of carefully designed and targeted BQ scales for gaining a deeper understanding of international performance differences. Given time constraints on respondents' time and the multiple functions served by the background questionnaire, priority should be given to identifying background characteristics and outcome measures that are also of importance to interpret the relevance of literacy and numeracy, but also some factors and outcomes, which may uniquely explain and be explained by APS.

Ideally, the background questionnaire should explore individual level determinants, covariates and precursors of APS, as well as environmental factors. At the individual level both personal background and personality attributes should be considered. As the contextual level, the quality of social relationships, the work environment and engagement in competency related practices at work and in everyday life should be considered.

Section 3 identifies a number of relevant cognitive and non-cognitive precursors. While it is acknowledged that there are a number of difficulties inherent in capturing relevant precursors – be they cognitive or non-cognitive – through self-reported BQ items, the list of cognitive (e.g. general knowledge, meta-cognitive strategy knowledge) and non-cognitive (e.g. achievement motivation, perseverance, problem solving self-concept) as put forward in Section 3 is an important starting point for consideration. Comprehensive coverage of a broad range of individual precursors needs to be carefully weighted against the need to include scales of sufficient length for each precursor. In particular for the non-cognitive precursors, established and validated self-report scales exist that should be considered for the BQ. Of note, there is some research on extracting cognitive performance through targeted self-report items and this might be a viable way of considering cognitive precursors within the BQ and without adding them as a time-consuming separate assessment scale. On a more general level, we would like to emphasise to rely to the largest extent possible on well validated and soundly developed questionnaire items that, if at all possible, exhibit strong ties to an underlying theory (as opposed to rather *ad-hoc* developed questions with unclear content and empirical validity) with the aim to have a conceptually clear BQ in the 2nd cycle of PIAAC.

As laid out in Section 6, disentangling ICT literacy from the assessment of problem solving is a particular relevant challenge given that digital channels are one of the most prevalent means through which problem solving takes place in the 21st century. To this end, several strategies on how to separate demands that are due to technology-rich environments and the actual demands that are due to APS processes are proposed in Section 6. One of them suggests gathering information on test-takers prior experience with and

use of ICT as part of their personal and professional life. Thus, assessment of ICT literacy including various aspects of it that range from prior experience through to self-reported ICT anxiety should play an important role in the BQ. This will inform not only our understanding of APS, but also our understanding of the role of ICT literacy for the computer-based assessments in general (cf. the work in the first PIAAC cycle).

The second aim of the BQ is gaining a more general understanding of how APS performance is embedded into the personal and professional lives of citizens across the countries participating in the 2nd cycle of PIAAC. To this end, self-report BQ items are an excellent means of collecting information on the typical surroundings and circumstances of peoples' lives that extend beyond the individual cognitive and non-cognitive precursors that were targeted in the first aim.

On a general level, examples of relevant areas that need coverage in the BQ are the home/private environment, the professional/school environment, and a number of relevant demographic variables as well as societal factors that might be relevant for understanding proficiency differences between countries. Obviously, when designing the BQ for all of these aspects, one can rely on the excellent work that has previously been conducted in the context of international large-scale assessments (one of them being the 1st cycle of PIAAC). As one general note, evaluation of significant others (within the family and beyond) as a complement to self-reports should be considered as an additional source of information to the extent practicable constraints allow (cf. also the consideration on the 1st cycle of PIAAC).

Beyond these general circumstances, it is important to understand how much and what kind of experience individuals gather across a range of problem-solving activities in their personal and professional lives. That is, beyond the rather general information mentioned in the previous paragraph and that can inform APS but also literacy and numeracy, additional information that is more closely related to specific problem-solving activities in everyday life is needed in the BQ. One aspect of peoples' everyday lives that is likely to influence the level of APS performance is frequency and quality of problem solving in personal and professional contexts. BQ items that are targeted at these aspects are likely to increase the understanding of how APS evolves and manifests itself through various contexts.

In summary, factors on several levels of abstraction ranging from core individual features all the way to the societal level might have an impact on APS as a complex set of skills comprised of several higher-order thinking processes. The background questionnaire is an important means of better understanding the nature of APS and the processes along which it evolves. Here, we argue that both adding new items that are specifically tailored towards the likely precursors of APS, as well as relying on existing work conducted in the first cycle of PIAAC and other large-scale assessments on the relevance of levels across a number of factors, will give invaluable information for a comprehensive understanding of APS across countries participating in the 2nd cycle of PIAAC.

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