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Assessing analytic and interactive aspects of problem solving competency

Andreas Fischer [a,*], Samuel Greiff [b], Sascha Wüstenberg [b], Jens Fleischer [c], Florian Buchwald [c], Joachim Funke [a]

[a] University of Heidelberg, Hauptstr. 47-50, 69117 Heidelberg, Germany
[b] University of Luxembourg, 6, rue Richard Coudenhove Kalergi, 1359 Luxembourg-Kirchberg, Luxembourg
[c] University of Duisburg-Essen, Berliner Platz 6-8, 45127 Essen, Germany

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ABSTRACT

This study is about different approaches to assessing Problem Solving Competency (PSC) applied in international large-scale assessments: Analytic Problem Solving (APS) and Interactive Problem Solving (IPS). Based on a university student sample (n = 339) and a high-school student sample (n = 577) we found that both approaches are highly interrelated in both samples, even after controlling for reasoning (R^2 = .33 to .52) indicating that both approaches address a common core of PSC. However, our results also indicate that unique aspects of APS and IPS (beyond each other and reasoning) are explanatory for school achievements in the high-school student sample. However, in the university student sample, only APS has a unique contribution to explaining school achievements (beyond IPS and reasoning) and our findings indicate, that APS – and not interactivity itself – may explain the incremental validity of IPS (beyond reasoning) reported in previous studies. Implications for problem solving research and educational practice are discussed.

1. Introduction

Solving real problems is a complex endeavor: Even the most intelligent persons can fail solving realistic and complex problems, if they don't have important content knowledge or don't know adequate search strategies as well as when to apply them in an adaptive way (cf. Dörner, 1996; Fischer, Greiff, & Funke, under review). This paper is about some of the most important components of Problem Solving Competency (PSC, cf. Fleischer, Wirth, & Leutner, 2014; Greiff & Fischer, 2013a; Wirth & Klieme, 2003) and their interrelations. Problem Solving Competency can be understood as the ability to figure out a solution method for reaching ones goal if no such method is obvious (cf., Duncker, 1945; Wirth & Klieme, 2003), that is, to represent and solve problems in various domains (cf. Bassok & Novick, 2012; Schoppek & Putz-Osterloh, 2003). In international large-scale assessments two different kinds of problems have been proposed for assessing PSC (OECD, 2014):

1) One kind of problem requires a single choice of a solution based on the information given at the outset. A characteristic example for this kind of problem is the problem of finding the shortest path between a set of locations based on a map before actually starting to travel. Problems of this kind can be solved analytically, as all the information required for finding a solution is given at the outset of the problem. We will refer to this kind of problem solving as *Analytic Problem Solving* (*APS*).
2) The other kind of problem requires a series of multiple choices, where later choices can be influenced by the results of previous choices (also known as Dynamic Decision Making, e.g., Gonzalez, Lerch, & Lebiere, 2003). For instance, after starting a travel, the initial plan of which locations to see may be adapted dynamically to unforeseen changes in the situation (e.g., road works on certain paths). In this kind of problem, the problem solver can adapt his or her initial plans and knowledge at multiple points in time, because there is feedback after each interaction with the problem. We will refer to this kind of problem solving as *Interactive Problem Solving* (*IPS*).

* Corresponding author at: Hauptstr, 47-50, 69117 Heidelberg, Germany. Tel.: +49 6221 547301; fax: +49 6221 547273.
E-mail addresses: andreas.fischer@psychologie.uni-heidelberg.de (A. Fischer), samuel.greiff@uni.lu (S. Greiff), sascha.wuestenberg@uni.lu (S. Wüstenberg), jens.fleischer@uni-due.de (J. Fleischer), florian.buchwald@uni-due.de (F. Buchwald), joachim.funke@psychologie.uni-heidelberg.de (J. Funke).

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Both kinds of problems[1] have been proposed to measure PSC, but up to now it has never been tested conclusively, if performance in both measures (APS and IPS) indicates distinct facets of PSC, or if they can be considered to address a common core of PSC (e.g., strategies for analyzing complex problem statements, or for systematically structuring prior knowledge and complex information in a goal-oriented way) sufficiently distinct from logical reasoning (Raven, 2000). In the *Programme for International Student Assessment* (PISA) 2012, both kinds of problems have been used to assess a single underlying PSC factor (OECD, 2014). The studies of Wirth and Klieme (2003) and Scherer and Tiemann (2014) presented first evidence for a multidimensional structure of PSC but they did neither control for reasoning nor analyze external validity of the facets reported.

In the current paper we will clarify the conceptual interrelations of reasoning and PSC and we will present empirical evidence based on two samples (577 high-school students and 339 university students) to demonstrate that APS and IPS address a common core of PSC that cannot be explained by reasoning, and that APS and IPS additionally address unique aspects each, which are important for explaining external criteria beyond reasoning. In the discussion we will focus on findings consistent between samples.

1.1. (Why) PSC is conceptually different from reasoning

It seems obvious that basic logical reasoning (e.g., forming inductive or deductive conclusions based on facts or premises, cf. Carpenter, Just, & Shell, 1990; Mayer, 2011), is closely related to problem solving (Mayer, 2011) and necessarily involved in each valid approach to assess PSC (cf. Greiff & Fischer, 2013a; Wüstenberg et al., 2012). However, in addition to this kind of reasoning PSC also implies a large amount of crystallized[2] abilities (Postlethwaite, 2011), that is, *"the knowledge and language of the dominant culture"* (Horn & Masunaga, 2006, p. 590). More specifically, solving problems in a competent way involves "experimental interactions with the environment" (Raven, 2000, p. 54) and depends on a large base of procedural and declarative knowledge on *how* and *when* to perform different search strategies in order to adequately represent and solve problems (e.g., Dörner, 1996). The importance of crystallized knowledge, especially knowledge about strategies, for PSC has often been emphasized (e.g., Scherer & Tiemann, 2014; Schoppek & Putz-Osterloh, 2003; Strohschneider & Guss, 1999; Tricot & Sweller, 2014) and is a central conceptual difference to basic logical reasoning.[3]

If this claim is correct, each valid operationalization of PSC should prove to be *incrementally* valid, compared to tests of reasoning with regard to external criteria such as academic or occupational success. To our knowledge, it is an open question if common variance between current instances of Analytic and Interactive Problem Solving (e.g., Scherer & Tiemann, 2014) can be attributed to reasoning only.

The present study aims to clarify if both APS and IPS are valid approaches to assessing PSC, that is, if they address "more than reasoning" (Wüstenberg et al., 2012) with regard to explaining (1) each other or (2) school grades (as external criteria of PSC).

1.2. Concept and empirical results concerning Analytic Problem Solving

For a long time, PSC has been assessed by APS tasks, that is, by confronting participants with multiple heterogenous problems each requiring a single solution to be generated analytically (e.g., Boggiano, Flink, Shields, Seelbach, & Barrett, 1993; Fleischer, Buchwald, Wirth, Rumann, & Leutner, under review; Fleischer, Wirth, Rumann, & Leutner, 2010; OECD, 2003). For instance, in PISA 2003 PSC was assessed by a set of multiple problems (OECD, 2003) that required (1) decision making under constraints, (2) evaluating and designing systems for a particular situation, or (3) trouble-shooting a malfunctioning device or system based on a set of symptoms (OECD, 2004, p. 61). All problems were designed to be realistic and refer to "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, 2003, p. 156; see also Leutner, Funke, Klieme, & Wirth, 2005a,b; Leutner, Wirth, Klieme, & Funke, 2005b).

Empirically, APS is highly correlated to performance in different domains like mathematics ($r = .89$), reading ($r = .82$) and science ($r = .80$) on a latent level (OECD, 2004, p. 55). Due to its broad operationalization APS is also closely related to – but yet empirically distinct from – reasoning ($r = .72$; Leutner, Klieme, Meyer, & Wirth, 2004; $r = .67$, Leutner, Fleischer, & Wirth, 2006; $r = .60$ Scherer & Tiemann, 2014). In general, APS seems to be more strongly related to intelligence and school achievements than IPS is (cf., Leutner et al., 2005a,b; Leutner, Fleischer, Wirth, Greiff, & Funke, 2012; Wirth & Klieme, 2003). To our knowledge there is no study explicitly examining the incremental value of APS over and above measures of reasoning and IPS.

1.3. Concept and empirical results concerning Interactive Problem Solving

IPS tasks are a more recent and computer-based approach to assessing PSC that evolved from research on Complex Problem Solving and Dynamic Decision Making (cf. Fischer, Greiff, & Funke, 2012). The defining feature of IPS is that the problem solver can not only rely on the information given at the outset, but must adapt his or her hypotheses (about how the problem works) and plans (about how to reach one's goals) while interacting with the problem (cf. Fischer et al., 2012; Klahr, 2000). Thus, the IPS approach focuses on effective strategies for searching the spaces of information and hypotheses as well as the resulting problem space (Greiff et al., 2013b). Fig. 1 illustrates an example of a typical interactive problem: This problem is an interactive computer-simulation based on a complex[4] abstract linear equation model (cf. MicroDYN approach, Greiff, 2012; Greiff, Fischer, Stadler, & Wüstenberg, in press). It is about a handball-team, that can be trained by applying different amounts of three different trainings (labeled A, B, & C), with each training possibly influencing motivation, power of throw and exhaustion of the team. The problem has to be solved in two subsequent phases: In a first phase, the problem solver can vary the values of certain input variables (in this case representing the amounts of three trainings, shown on the left side of the screen in Fig. 1), and observe the values of certain output variables (on the right side of the screen in Fig. 1). In this phase, his or her goal is to find out about the causal structure of the simulation and to draw his or her hypotheses into a causal model at the bottom of the screen (*problem representation*, sometimes referred to as knowledge acquisition, see Fig. 1). In a subsequent phase the problem solver is instructed to reach a set of well-defined goals (see the values in brackets in Fig. 1) by

[1] In the literature on complex problem solving (e.g., Funke, 2003; Scherer & Tiemann, 2014) and dynamic decision making (e.g., Edwards, 1962), sometimes APS and IPS have also been referred to as static vs. dynamic decision problems, or as simple vs. complex problems, respectively.

[2] Traditional measures of "crystallized intelligence" are often tests of highly *general declarative* knowledge. They focus on breadth instead of depth of the individual's knowledge base (i.e., they "measure only the elementary knowledge, the beginning [declarative] knowledge, in the various fields of human culture", Horn & Masunaga, 2006, p. 597). The *concept* of crystallized intelligence represents a broader and more diverse range of knowledge (Horn & Masunaga, 2006) — e.g., procedural knowledge as it is tapped by some tests of expertise or PSC, for example.

[3] As a result of these crystallized aspects, PSC can be assumed to be less domain-general than reasoning as well as more prone to training (cf. Scherer & Tiemann, 2014).

[4] Of course one could also simulate even more complex problems containing aspects like negative feedback (e.g., predator–prey-systems, Cushing, 1977; or the sugar-factory-simulation, Berry & Broadbent, 1984), phase transitions, or deterministic chaos (e.g., Verhulst, 1839) within the framework proposed by Funke (2001) but each of these aspects again is likely to address additional or different skills and strategies. Traditional MicroDYN tests seem to reliably address a small set of skills (cf. Greiff & Fischer, 2013a,b; Funke, 2010), that are central for solving a wide range of analytic and/or complex problems.