Intelligence 54 (2016) 55–69

Contents lists available at ScienceDirect

Intelligence

Construct validity of complex problem solving: A comprehensive view on different facets of intelligence and school grades☆,☆☆

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ARTICLE INFO

Article history:
Received 12 June 2015
Received in revised form 21 October 2015
Accepted 18 November 2015
Available online xxxx

Keywords:
Complex problem solving
Intelligence
School grades
Nested factor model
Validity

ABSTRACT

Although complex problem solving (CPS) has attracted increasing amounts of attention in recent years (e.g., in the PISA study), the role of CPS in the nomological network of intelligence is controversial. The question of whether CPS is a distinct construct is as old as CPS research itself, but previous studies have had specific shortcomings when addressing the question of whether CPS is a separable or independent construct. The aim of the present study was, therefore, to combine the advantages of previous studies to facilitate a less biased view of the relation between CPS and established intelligence constructs. A sample of 227 German university students worked on a comprehensive measure of intelligence (Berlin Intelligence Structure test) and two CPS assessment tools (MicroDYN and MicroFIN). Furthermore, final school grades (GPA) served as an external criterion. We applied confirmatory factor analyses and structural equation modeling to investigate the relation between CPS and established intelligence constructs on the basis of different psychometric approaches (i.e., first-order model, nested factor model). Moreover, we examined the incremental validity of CPS in explaining GPA beyond established intelligence constructs. Results indicate that CPS represents unique variance that is not accounted for by established intelligence constructs. The incremental validity of CPS was found only when a commonly used narrow operationalization of intelligence was applied (i.e., figural reasoning) but not when a broad operationalization was applied.

In spite of the increasing popularity of complex problem solving (CPS),[1] especially in the educational sciences and international large-scale assessments such as the Programme for International Student Assessment (PISA; OECD, 2014), the status of CPS in the nomological network of intelligence is still controversial. Problem solving, in general, is seen as an essential part of intelligence (Gottfredson, 1997). However, there is a long-standing debate about whether CPS is just a new label for established constructs such as reasoning (fluid intelligence; e.g., Kröner, Plass, & Leutner, 2005; Süß, 1996) or a distinct cognitive construct not yet covered by established intelligence theories (e.g., Greiff, Wüstenberg, et al., 2013; Wüstenberg, Greiff, & Funke, 2012).

CPS describes the ability to solve unknown problem situations that are intransparent, dynamic, and interactive (e.g., Dörner, Kreuzig, Reither, & Stäudel, 1983, Frensch & Funke, 1995). This means, for instance, that relevant information needed to solve the problem is hidden from the outset (e.g., a new technical device without a manual). In order to solve the complex problem situation, the problem solver therefore needs to actively explore the problem situation to acquire knowledge (e.g., the functionality of controls). In a subsequent step, he or she can then use the acquired information to actually solve the problem (i.e., apply knowledge; Fischer, Greiff, & Funke, 2012). Accordingly, Wüstenberg et al. (2012) and Greiff, Fischer, Stadler, and Wüstenberg (2014) stated that the cognitive requirements associated with these dynamic interactions make CPS a separable construct as opposed to, for example, reasoning, which is usually measured with static tasks (e.g., all information needed to solve the problem is present and, thus, no new knowledge has to be acquired by interacting with the problem at hand).

On the other hand, the status of CPS in the nomological network of intelligence can also be viewed from a different angle (e.g., Kersting, 2001, Kröner et al., 2005, Süß, 1996). From this perspective, CPS is basically understood as a new label for or a conglomerate of already established

☆ We are grateful to the TBA group at DIPF (http://tba.dipf.de) for providing the authoring tool CBA Item Builder and technical support. We would also like to thank the various student assistants who assisted with the data collection and the data preparation and Philipp Sonnleitner for his comments on an earlier version of the manuscript. The data collection was part of the first author's dissertation.
☆☆ This research was partly funded by a grant from the Fonds National de la Recherche Luxembourg (ATTRACT "ASKI21").
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[1] Although we use the term *complex problem solving*, there are several synonyms in the literature, for example, interactive problem solving (e.g., Fischer et al., 2015), dynamic problem solving (e.g., Greiff et al., 2012), creative problem solving (e.g., OECD, 2014), or even dynamic decision making (e.g., Gonzalez, Thomas, & Vanyukov, 2005).

http://dx.doi.org/10.1016/j.intell.2015.11.004
0160-2896/

cognitive constructs. Reasoning, defined as "the use of deliberate and controlled mental operations to solve novel problems that cannot be performed automatically" (McGrew, 2009, p. 5), is thereby seen as a major cognitive ability that already includes the cognitive processes necessary to solve complex problems, including requirements such as the need to actively acquire knowledge. Consequently, some argue that the nomological network of intelligence does not need the distinct cognitive construct of CPS.

These two different perspectives (i.e., the arguments for a distinct CPS construct vs. the redundancy of CPS) have resulted in a controversial discussion that has existed since the beginning of CPS research (e.g., Dörner et al., 1983, Funke, 1999, Süß, 1996, Wüstenberg et al., 2012). Although both perspectives appear reasonable, previous studies from each perspective have their drawbacks. For example, the generalizability of previous findings is limited by psychometrically suboptimal CPS assessment tools, restricted operationalizations of intelligence, a lack of analyses on relations between CPS and external criteria, and a focus on specific psychometric approaches.

The purpose of the present study was to overcome these limitations and, thus, to shed further light on the issue of a distinct CPS construct, both theoretically and empirically. To do so, we address the origins of both perspectives and their empirical findings in the next section before presenting our empirical investigation.

1. Complex problem solving and intelligence: two perspectives

1.1. Redundancy perspective: complex problem solving as intelligence

From a theoretical point of view, it can be argued that there is a substantial overlap between CPS and established constructs of intelligence, in particular, reasoning. Mental operations such as drawing inferences, generating and testing hypotheses, identifying relations, comprehending implications, problem solving, extrapolating, and transforming information are seen as the core processes of reasoning (McGrew, 2009). At the same time, these operations closely correspond with the main mental operations applied in CPS (see Fischer et al., 2012; Greiff, Fischer, et al., 2014). Accordingly, Süß (1996, 1999) explicated that primarily processes of inductive and deductive reasoning are necessary to solve complex problems (e.g., detecting relations between a set of variables in a complex and dynamically changing system). However, the overlap between intelligence constructs and CPS is not limited to aspects of reasoning. Süß (1996) mentioned that additional intelligence constructs such as mental speed and crystallized intelligence (i.e., general and domain-specific knowledge) might also be involved if time constraints exist or if domain-specific problems need to be solved. In summary, CPS could be seen as a new (but redundant) label for established intelligence constructs or a conglomerate of them but not as a new construct that justifies the extension of current theories of intelligence.

This view has been empirically underpinned by several studies. For example, Süß (1996) demonstrated manifest correlations between a comprehensive operationalization of intelligence (i.e., reasoning, mental speed, memory, and creativity on the Berlin Intelligence Structure Test, BIS; Jäger, Süß, & Beauducel, 1997; Süß & Beauducel, 2015; as well as several tests of crystallized intelligence) and CPS (assessment tool: Tailorshop; Putz-Osterloh, 1981) up to $r = .65$, an overall amount of variance explained in CPS in a multiple regression with different facets of intelligence of up to 51%, and no significant correlation between two measures of CPS at different points in time when controlling for these facets of intelligence. Other studies (Süß, 1999; Wittmann & Süß, 1999) found manifest correlations between established intelligence constructs (BIS test) and several instruments targeting CPS (assessment tools: LEARN!, Milling, 1996; Tailorshop, Putz-Osterloh, 1981; PowerPlant, Wallach, 1997) of up to $r = .56$ and about 32% variance explained in CPS. Again, the correlations between CPS measurement instruments were nonsignificant when the broad operationalization of intelligence using the BIS test was controlled for. Other studies from this perspective did not even distinguish between CPS and intelligence but rather used CPS assessment tools as interactive measures of reasoning. For instance, Kröner et al. (2005) interpreted manifest correlations between CPS (assessment tool: MultiFlux; Kröner, 2001) and reasoning (BIS subscale) of $r = .67$ as evidence for convergent validity between two different intelligence measures—one using a classical paper-pencil test and one using a computer-based dynamic assessment environment.

In summary, studies from the redundancy perspective have reported (mainly manifest) high correlations between established intelligence constructs and CPS. In fact, these correlations were described as being as high as "[…] one would expect from a typical correlation between conventional intelligence tests" (Kröner et al., 2005, p. 365). In addition, it was argued that systematic variance in CPS could be fully explained with established intelligence constructs (Kersting, 2001; Süß, 1996, 1999). Both criteria (i.e., the high correlation between intelligence measures and CPS and the absence of systematic CPS variance) led to the conclusion that there was no evidence for a specific CPS construct.

1.2. Distinctness perspective: complex problem solving as a separate construct

Acknowledging the studies mentioned above, proponents of the distinctness perspective confirmed an overlap between CPS and established intelligence constructs but emphasized the unique cognitive requirements of CPS. According to this perspective, solving a complex problem requires the problem solver to deal with a lack of information at the outset, actively generate information, deal with dynamic interactions, and use procedural knowledge (Greiff, Fischer, et al., 2014a; Putz-Osterloh, 1981). Thus, more complex cognitions must be involved in CPS to handle the dynamic interactions in complex problems—in particular in comparison with simple cognitions (e.g., processing capacity, mental speed; see Funke, 2010), which would be fairly well-covered by traditional intelligence tests such as Raven's Advanced Progressive Matrices (APM; Raven, 1958). In other words, the argument is that established constructs of intelligence might not be sufficient to cover the mental processes involved in CPS. Hence, CPS is seen as a distinct construct: located in the nomological network of intelligence but separable from established constructs such as reasoning. It is important to note that agreement has not been achieved about exactly where to locate CPS in concurrent theories of intelligence (see Danner, Hagemann, Schankin, Hager, & Funke, 2011; Wüstenberg et al., 2012).

The distinctness perspective has also been empirically supported by a number of studies. For example, Wüstenberg et al. (2012) reported a latent correlation between figural reasoning (APM) and CPS (assessment tool: MicroDYN; Greiff, Wüstenberg, & Funke, 2012) of up to $r = .63$ and a proportion of variance explained in CPS of up to 39%. Furthermore, a significant and strong correlation between tasks targeting CPS and even between two CPS subprocesses (i.e., knowledge acquisition and knowledge application; Fischer et al., 2012) were also found when controlling for figural reasoning ability. In contrast to previous studies, Wüstenberg et al. (2012) additionally reported incremental predictive validity[2] for CPS. CPS explained incremental variability in final school grades (grade point average; GPA) beyond figural reasoning (6% additional explained variance), indicating an incremental utility of CPS beyond an established intelligence construct. Other studies have replicated these findings several times (e.g., Greiff, Fischer, et al., 2013; Greiff, Wüstenberg, et al., 2013). In a different study, Danner, Hagemann, Holt, et al. (2011) reported manifest correlations between figural reasoning (APM) and two instruments targeting CPS (assessment tools: Tailorshop, Putz-Osterloh, 1981; HEIFI, Wirth & Funke, 2005) of up to $r = .55$ and interpreted this finding as indicative of separable

[2] The term *predictive* intuitively belongs to longitudinal studies, but it is often used in cross-sectional studies as well (e.g., Wüstenberg et al., 2012). Following this practice, it is also used here for statistically explaining variance in criteria.