Intelligence 63 (2017) 1–8

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

Metacognitive confidence judgments and their link to complex problem solving

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ARTICLE INFO

Keywords:
Response confidence
Complex problem solving
Reasoning
Metacognition

ABSTRACT

With the aim to better understand the nature of complex problem solving (CPS), we investigated the link between confidence judgments, which represent a major constituent of metacognitive self-monitoring, and CPS by regressing the two facets of CPS (i.e., knowledge acquisition and knowledge application) on confidence in CPS. To ensure that the link between confidence in CPS and CPS is distinct, we controlled for reasoning, which is the strongest known correlate of CPS. Using structural equation modeling in a sample of 471 German seventh-grade students, we found that confidence in CPS explained 67% of the variance in CPS knowledge acquisition and 55% of the variance in CPS knowledge application. These links were reduced but remained substantial when we controlled for reasoning. The results indicate that confidence judgments as indicators of metacognitive monitoring in CPS are substantially linked to successful CPS, thus bringing us one step closer to a full understanding of CPS.

1. Introduction

Complex problem solving (CPS) describes the process of successfully interacting with nonroutinely encountered and dynamically changing environments (Buchner, 1995). As such, CPS is needed in a variety of situations that virtually all students face in their everyday lives. For instance, CPS is required when students use new technological devices (smartphones, computer programs, etc.; Wüstenberg, Greiff, & Funke, 2012) and is needed to cope with everyday life in professional, private, and educational settings. Its relevance has been recognized in educational research (Greiff et al., 2013), and a large body of research has recently emerged to try to understand the nature of CPS by focusing on the relation between CPS and concurrent cognitive skills (Kröner, Plass, & Leutner, 2005). One overarching finding is that CPS overlaps substantially with reasoning. However, reasoning does not account for all of the variance in CPS (e.g., see the meta-analysis by Stadler, Becker, Gödker, Leutner, & Greiff, 2015). This coincides with CPS theory, which proposes that constructs other than reasoning play important roles in CPS. In particular, self-regulation, the skill that is used to monitor and adapt one's problem-solving strategies, should be a central component of CPS (Funke, 2003; Ifenthaler, 2012; Mayer, 1998; Wüstenberg, Stadler, Hautamäki, & Greiff, 2014). In CPS, it is likely that students do not apply expedient systematic approaches for investigating dynamic problem characteristics from the very beginning. Thus, they need to realize that they have to continuously adapt their problem-solving behavior to be successful in CPS.

Among the core aspects of self-regulation is metacognitive self-monitoring, that is, the observing and judging of one's own performance (Fritzsche, Kröner, Dresel, Kopp, & Martschinke, 2012; Stankov, 2000; Stankov, Lee, Luo, & Hogan, 2012). Both performance judgments and self-reported confidence have been shown to be both economic and valid indicators of metacognitive self-monitoring (Fritzsche, et al., 2012; Händel, & Fritzsche, 2016; Stankov, 2000).

In the present study, we investigated whether and to what extent metacognitive monitoring in complex problem solving is linked to overall performance in CPS. Moreover, we aimed to take the first steps toward ensuring that such a link cannot be ascribed to reasoning, which is at the core of intelligence (Carroll, 2003) and is a strong and well-known correlate of CPS (see the meta-analysis by Stadler et al., 2015).

1.1. Confidence in CPS and CPS

In more detail, CPS reflects the skill needed to understand and to subsequently control dynamic environments that require the problem

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http://dx.doi.org/10.1016/j.intell.2017.04.005
Received 2 May 2016; Received in revised form 9 April 2017; Accepted 10 April 2017
Available online 05 May 2017
0160-2896/

solver to actively interact with this environment (Buchner, 1995) in a situation in which not all the information that is needed to control the environment is apparent from the beginning and has to be discovered through active interaction (Funke, 2001). CPS research focuses on two central and intertwined facets of CPS: knowledge acquisition and knowledge application (e.g., Greiff, Kretzschmar, Müller, Spinath, & Martin, 2014; Greiff et al., 2013; Kröner et al., 2005). Successful knowledge acquisition is a skill that enables people to explore and understand the functioning of a complex system, whereas knowledge application is needed to be able to use one's understanding of the environment to control it. To give an example, if students have to edit pictures with an unfamiliar picture editor, they need to explore and understand the functions of the editor (knowledge acquisition) and subsequently use the acquired knowledge to control the editor (knowledge application).

Research that is aimed at understanding CPS has had a strong focus on the relations between CPS and other cognitive ability measures with a particular focus on reasoning because reasoning is a central component of intelligence (Carroll, 2003). One often-reported finding is that CPS overlaps substantially with cognitive ability measures, in particular with reasoning (Kröner, et al., 2005), whereas there is also some evidence for the unique explanatory value of CPS regarding external outcomes such as academic achievement (e.g., Greiff et al., 2013; Wüstenberg et al., 2012; cf. Kretzschmar, Neubert, Wüstenberg, & Greiff, 2016). However, numerous scholars have noted that other constructs may also be important for CPS, including noncognitive aspects. For instance, CPS is supposed to be highly relevant for metacognition (e.g., Funke, 2003; Ifenthaler, 2012; Huber, 1995; Mayer, 1998), which is the "cognition that reflects on, monitors, or regulates first order cognition" (Kuhn, 2000, p. 178; see also Flavell, 1979; Kleitman, & Gibson, 2011; Schraw, Crippen, & Hartley, 2006). Conceptually, metacognition is intertwined with skill in revising and evaluating tasks, goals, and strategies (Flavell, 1979). As problem solving requires such metacognitive skills to apply or adapt problem-solving strategies whenever necessary (Ifenthaler, 2012), it is conceptually linked to metacognition. Moreover, complex problems may particularly require metacognitive self-monitoring skills (Vollmeyer & Rheinberg, 1999) because students might be overwhelmed by the quantity of information that has to be tackled (Zimmermann & Campillo, 2003).

As metacognition requires skill in evaluating and adapting the process of problem solving, one aspect that is at the core of metacognition is one's judgment of one's own performance (Stankov, 2000). Throughout a large part of the literature, confidence is defined as "a state of being certain about the success of a particular behavioral act" (Stankov et al., 2012, p. 1). That is, it may be considered a combination of (a) a performance judgment and (b) certainty about this judgment. To disentangle these two aspects, in the present paper, we focused on the first aspect of confidence. For instance, during each CPS task we assessed the students' confidence by asking them whether they thought they were solving it correctly. This aspect of confidence should be a central aspect of CPS because CPS constantly requires accurate performance judgments (Funke, 2003; Greiff & Fischer, 2013; Huber, 1995), and effective problem solvers should evaluate their performance during problem solving to decide whether they should continue following the strategy they chose or whether an adaptation is needed (Funke, 2003; Mayer, 1998). Thus, the correct estimation of their performance should foster successful CPS.

At the same time, confidence may be influenced by students' CPS performance. For example, if students are aware that they are usually successful in problem solving, they may be more likely to provide positive performance judgments during problem solving tasks. This is particularly pertinent to CPS (as opposed to static problem solving) because CPS tasks offer a large number of task-inherent cues due to their dynamic and interactive character: Students may be aware that they are on the right track on the basis of task-inherent cues (Kröner & Biermann, 2007). For instance, if the complex problem was to attach a blue frame to a picture with an unfamiliar picture editor and students have figured out how to attach a red frame, they might be aware that they are on the right track. Moreover, complex tasks enable students to verify their acquired knowledge. For instance, if students wish to verify that they know how to attach a blue frame, they can attach the frame to another picture.

Taken together, theory suggests a strong mutual link between CPS and confidence in CPS, and this should translate into a unique statistical effect when trying to explain variance in CPS performance with confidence in CPS. Whereas such a link between confidence and CPS has not been investigated empirically, confidence in cognitive tests has been shown to be substantially associated with other skills such as reasoning and perception (Kröner & Biermann, 2007) as well as writing, speaking, and numeracy (Stankov & Lee, 2008). Further, Kleitman and Gibson (2011) and Kleitman and Moscrop (2010) reported that test-specific confidence is linked to students' grades in mathematics, spelling, and reading, making it seem likely that confidence in CPS is linked to CPS performance. Altogether, we hypothesized that confidence in CPS would explain variance in the CPS facets knowledge acquisition and knowledge application as well as in CPS variance that is shared by the two facets (Hypothesis 1).

1.2. Reasoning, confidence in CPS, and CPS

In a second step, we aimed to put any gain in knowledge about the link between confidence and CPS performance (Hypothesis 1) together with the most established correlate of CPS: reasoning. As indicated above, researchers who have previously attempted to understand the nature of CPS have come to the conclusion that reasoning is a crucial constituent of CPS (see the meta-analysis by Stadler et al., 2015) because both reasoning and CPS require the abilities to identify relevant information (Babcock, 2002; Funke, 2001) and to elaborate and apply strategies to solve problems (Wüstenberg et al., 2012).

Nevertheless, reasoning and CPS differ conceptually with regard to additional requirements because all information that is needed to solve the problem is given at the outset for reasoning tasks but not for CPS tasks (Greiff et al., 2014; Wüstenberg et al., 2012; cf. Kretzschmar et al., 2016; Wittmann & Süß, 1999). Complex problems actively generate the particular situations that provide the relevant information needed to solve the problems. Thus, CPS demands an active and systematic search for missing information and the skill needed to control dynamic environments that change with time or as the problem solver interacts with them (Wüstenberg et al., 2012).

Empirically, the investigation into whether reasoning and CPS differ is often conducted by regressing the CPS facets of knowledge acquisition and knowledge application on reasoning (e.g., Greiff et al., 2014; Greiff et al., 2013; Kröner et al., 2005; Wüstenberg et al., 2012). The overall findings of such studies were that reasoning could not account for all of the variance in knowledge acquisition and knowledge application and that the two facets remained correlated when reasoning was controlled for. This indicates that the facets share CPS-specific variance that goes beyond reasoning. As Kröner (2014) stated, this variance might be partially explained by self-evaluation as a core aspect of self-regulation, which can be operationalized via CPS performance judgments. Thus, we hypothesized that confidence in CPS and CPS would be linked beyond reasoning. In particular, we expected that including confidence in CPS would explain variance in the CPS facets knowledge acquisition and knowledge application as well as CPS variance that is shared by the two facets beyond reasoning (Hypothesis 2).

1.3. Hypotheses

With the present research, we aimed to explore the nature of CPS by investigating its link to metacognitive confidence judgments in CPS. To