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Evidence on the effects of task interactivity and grade level on thinking skills involved in complex problem solving

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ABSTRACT

The present study aims to analyze the structure of problem solving abilities which can be regarded as higher-order thinking skills in the domain of science. We investigate the effects of task interactivity and grade level on problem solving and check whether a method factor of task interactivity improved our proposed model. 805 high-school students of grades 8 and 10 worked on a computer-based assessment and completed tests on related constructs such as intelligence, domain knowledge, and strategy knowledge in science. Using confirmatory factor analysis, we established a measurement model with three correlated traits, one method factor of interactivity, and grade level as a predictor. Our results suggest that: (1) scientific problem solving can be regarded as a multidimensional construct, (2) task interactivity is a substantial factor in determining students' problem-solving success, and (3) there is a development within the analytical component of problem solving across grades. We conclude that psychological theories of problem solving and interactivity can be transferred to complex problem-solving situations in the domain of science.

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1. Introduction

The ability to solve complex problems is one of the key competencies in science. Especially in large-scale assessments such as the Programme for International Student Assessment (PISA), researchers and policy-makers have focused on the assessment of how students solve real-world problems (OECD, 2013). In this context, problem solving has been largely defined as the ability to bridge the gap between an initial and a goal state by performing cognitive operations (Novick & Bassok, 2005). These operations require far more than the reproduction of knowledge. Students also have to apply and acquire knowledge in order to reason scientifically, which is one of the key concepts in science education (Abd-El-Khalick et al., 2004; Wüstenberg, Greiff, & Funke, 2012).

Understanding the cognitive processes, which are involved in problem solving, and analyzing the structure of scientific problem solving has been a challenge in psychology and science education. Although research on problem solving also focuses on the question of whether the construct is represented by a single factor or different traits, there is a gap between theoretical assumptions on the structure of the construct and testable measurement models (Ragni & Löffler, 2010).

There have been attempts to describe the structure of problem-solving processes from psychological and educational perspectives. Psychological studies provided evidence that problem solving is a multidimensional construct and not a single latent trait (Bühner, Kröner, & Ziegler, 2008; Kröner, Plass, & Leutner, 2005). These approaches are regarded as *domain-general*

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(OECD, 2013). But as Jonassen (2011) argued, the ability to solve complex scientific problems requires domain knowledge and knowledge about the structure of the problem. Both types of knowledge are strongly related to conceptual understanding. Scientific problem solving is, thus, regarded as *domain-specific* (Lee, Jonassen, & Teo, 2011). For example, Klahr (2000) developed a model for science, which systematically takes into account domain-specific knowledge and strategies, and further distinguishes between cognitive components of the construct. Together with other approaches and conceptualizations in science (e.g., Piekny & Maehler, 2012; Zimmerman, 2007), these models mainly focus on the description of analytical problem solving, which is closely related to scientific reasoning. Also, domain-specific research on problem solving largely ignored the cognitive processes of interacting with a complex system (Friege & Lind, 2006; Hambrick, 2005). Additionally, it is still unclear whether or not cognitive models of the domain-general perspective could be transferred and applied to specific domains such as science. Until now, there have been only a few approaches of transferring psychological models and assessments into context-based scenarios (e.g., Sonnleitner, Keller, Martin, & Brunner, 2013). Consequently, a systematic combination of both approaches is still missing.

Research on the development of scientific problem solving has shown that there are two sources of variability across age (Amsel et al., 2008). First, there are task-specific characteristics such as the interactivity of a certain problem or system, which lead to different forms of problem solving (Funke, 2010). Especially, psychological research has focused on the description of complex and interactive problem solving (e.g., Kröner et al., 2005; Wüstenberg et al., 2012). But these approaches mostly ignored the effects of interactivity on measurement models. In this context, task interactivity refers to a system property which allows students to specify inputs, subsequently leading to system feedback. Based on this feedback, an output is generated, which forms the basis for understanding how the system works. For instance, Wüstenberg et al. (2012) used virtual microworlds which contained systems such as a cell phone or an mp3 player. In scientific domains, Scherer (2012) proposed microworlds which represented analytical devices in chemistry. However, these interactive systems were unknown from the beginning of the problem solving process.

Second, there is an age-related variability in terms of when and how the development of scientific problem solving occurs across the life-span (Amsel et al., 2008; Piekny & Maehler, 2012; Zimmerman, 2007). In domain-general contexts, Molnár, Greiff, and Csapó (2013) showed that students' performance increased with age. But the differences across grade levels have not yet been investigated among the components of domain-specific problem solving in science.

Consequently, this study aims to combine psychological and educational approaches of modeling scientific problem solving by proposing a framework that distinguishes between different components of the construct. Furthermore, we systematically analyze the effects of task interactivity and grade level. Our study, therefore, contributes to the field of the assessment of and influences on complex problem solving as a higher-order thinking skill.

1.1. *Models of scientific problem solving*

In this section, we review domain-general and domain-specific models in order to establish a model for scientific problem solving which combines both approaches.

There have been various domain-general approaches of modeling problem solving which mainly focused on the description of cognitive processes of the construct. For example, psychological studies conducted by Kröner et al. (2005) and Wüstenberg et al. (2012) provided evidence that the ability to solve complex problems comprises three general components: (1) Identifying rules and relationships among variables within a system (Rule identification), (2) acquiring knowledge about the system (Rule knowledge), and (3) applying rule knowledge in order to achieve a goal state, which represents a solution of the problem (Rule Application). Bühner et al. (2008) followed a similar approach and argued that the acquisition of rule knowledge, which determines the application of rules in an interactive problem-solving environment, strongly depends on general intelligence and working memory. In these models, problem solving is regarded as an ability to acquire and apply system knowledge within intransparent and complex scenarios (Funke, 2010). Furthermore, researchers argued that this type of knowledge would be necessary in order to solve the problem successfully (e.g., Wüstenberg et al., 2012). However, Goode and Beckmann (2010), Scherer and Tiemann (2012), and Schoppek (2002) found that knowledge about a system does not necessarily lead to a successful problem solution. Instead, they argued that task-specific knowledge must be available prior to the problem-solving process.

Bulu and Pedersen (2012) as well as Lee et al. (2011) underlined these arguments and stressed that problem solving should be operationalized as a domain-specific construct because domain knowledge and conceptual understanding are involved. Researchers, therefore, developed models and assessments of problem solving for specific domains such as mathematics (e.g., Rozencwajg & Fenouillet, 2012; Xin & Zhang, 2009) and science (e.g., Hoffman & Schraw, 2009; Klahr, 2000; Scherer & Tiemann, 2012). These models systematically take into account conceptual understanding, domain knowledge, epistemological knowledge, and domain-specific problem-solving strategies. For example, Klahr (2000) proposed a framework of scientific problem solving by distinguishing between three sub-abilities: generating hypotheses, experimentation, and evaluating evidence. Wellnitz, Hartmann, and Mayer (2010) systematically built upon this concept and showed that such a model could be applied in biological contexts. However, the concept of domain specificity has not yet been addressed systematically for the construct of problem solving (Jonassen, 2011).

While performing a problem-solving process, different kinds of cognitive operations and influences of covariates come together. As research suggested, cognitive constructs such as fluid intelligence and domain knowledge significantly affect students' problem-solving success in a positive direction (e.g., Funke & Frensch, 2007; Wilhelm, 2005; Wu & Pedersen,

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