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A field experimental study of analytical problem solving competence—Investigating effects of training and transfer

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ABSTRACT

Problem solving is a key concept used to cope with the demands of a rapidly changing world. It is regarded both as a cross-curricular competence that is related to, but not identical to, general cognitive abilities, and as a domain-specific competence (e.g., in mathematics). Based on results of the Programme for International Student Assessment (PISA) 2003 and a connected repeated measurement study in Germany (PISA-I-Plus), the cognitive potential exploitation hypothesis postulates that crosscurricular analytical problem solving competence can be regarded as a resource for improving domainspecific problem solving competence in mathematics. The paper presents results from a 15-week field experimental training study ($N = 173$ students in Grade 9) investigating aspects of this hypothesis by addressing this research question: can broad training in cross-curricular analytical problem solving with a focus on conditional knowledge, procedural knowledge, and planning skills enhance (1) cross-curricular analytical problem solving and (2) mathematical problem solving? The results show an interactive effect between treatment and prior cross-curricular problem solving competence indicating an effect of transfer for low-achieving problem-solvers on mathematical problem solving competence. The results are discussed from both an educational research and an instructional perspective.

1. Introduction

In the twenty-first century, general competencies with a broad scope like problem solving are particularly important for coping with a rapidly changing and complex society (Klieme, 2004). On the one hand, problem solving is regarded as a cross-curricular competence that is important for successful learning at school, at work, and in different areas of daily life (OECD, 2004b, 2013; see also Levy & Murnane, 2005). On the other hand, the fostering of problem solving as a subject-specific competence is a crucial educational goal in various subject areas such as mathematics and science (e.g., AAAS, 1993; Blum, Drüke-Noe, Hartung, & Köller, 2006; NCTM, 2000). On account of the crucial importance of problem solving as a cross-curricular as well as a subject-specific competence, problem solving has become a test domain in international large-scale assessments, as in the Programme for International Student Assessment (PISA; OECD, 2004b, 2013).

Results from PISA 2003 showed considerable differences between students' mean performance in mathematics and cross-curricular problem solving in many countries in favor of cross-curricular problem solving (e.g., in Germany) although the latent correlation of both scales was rather high ($r = 0.89$; OECD, 2005). This difference can be interpreted as an indication

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that students have 'generic skills that may not be fully exploited by the mathematics curriculum' (OECD, 2004b, p. 56). Mean differences between mathematics and cross-curricular problem solving in favor of mathematics (e.g., in the Netherlands) can be interpreted as an indication that 'mathematics instruction is relatively effective in helping students reach their potential' (OECD, 2004b, p. 55; for an alternative interpretation see the Section 4).

The current study is the first attempt to investigate aspects of this 'cognitive potential exploitation hypothesis' (Leutner, Klieme, Meyer, & Wirth, 2004; OECD, 2004b) in a field experimental setting.[1] Since the hypothesis refers to results of PISA 2003 which are based on analytical problem solving we will focus on this aspect.

In analytical problems all information needed to solve the problem is explicitly stated or can be inferred from the given problem situation (OECD, 2004b; e.g., allocating people to bedrooms in a holiday camp when all constraints like number of people, room capacity, etc., are given). Analytical problem solving can thus be seen as the reasoned application of existing knowledge (OECD, 2004b; Wirth & Klieme, 2003). Typical cognitive demands of these kinds of problems are structuring, representation and integration of information (Wirth & Klieme, 2003).

Contrary, dynamic or complex problems (e.g., Greiff et al., 2013b) require an explorative interaction with the problem situation to generate the information needed to solve the problem ('learning by doing'; Wirth & Klieme, 2003). For example, in order to solve the problem of buying the cheapest train ticket from stations A to B at a ticket machine (OECD, 2014) the problem-solver has to interact in some way with the problem (e.g., using the menu of the ticket machine) which changes the problem state (e.g., new menus or interface language). Examples of measurement approaches to complex problem solving are microworld simulations such as tailorshop (Danner et al., 2011; Putz-Osterloh, 1981), minimal complex systems (MicroDYN; Greiff & Funke, 2009), and finite automata (Buchner, 1999). For a more detailed theoretical discussion of analytical and dynamic aspects of cross-curricular problem solving in the context of PISA studies see Greiff, Holt, and Funke (2013a).

1.1. Cross-curricular problem solving and mathematical problem solving in PISA 2003

Since PISA 2003, research on problem solving competence in the context of school and educational systems has received growing attention (OECD, 2014). Successful cross-curricular problem solving requires a person to (1) understand, (2) characterize, (3) represent and (4) solve the problem, (5) reflect and (6) communicate the problem solution (OECD, 2003). Descriptions of the mathematical modelling cycle, which is the theoretical basis for the PISA 2003 mathematics assessment, comprise comparable steps: (1) starting with a problem situated in reality, (2) organizing it according to mathematical concepts, (3) gradually trimming away the reality through processes such as making assumptions about which features of the problem are important or through generalizing and formalizing, (4) solving the mathematical problem and (5) making sense of the mathematical solution in terms of the real situation (OECD, 2003). The close relation between cross-curricular problem solving and mathematics problem solving also becomes evident when one looks at the cognitive resources required to solve mathematics and cross-curricular problem solving tasks. According to the PISA 2003 assessment framework (OECD, 2003), both require low reading competencies, no scientific knowledge, but high analytical reasoning ability. The main difference is the number of mathematical operations needed. Cross-curricular problem solving tasks are limited to simple mathematical operations whereas mathematics problem solving tasks require mathematical content beyond the level of simple operations (OECD, 2003). The latent correlation of $r = 0.89$ between cross-curricular problem solving competence and mathematical competence shows the similarity of these domains empirically (OECD, 2005). On the other hand, this rather high correlation does not question the discriminant validity of the cross-curricular problem solving test since it is still within the range of the correlations of the other test domains in PISA 2003 (OECD, 2005, p. 189). See also the results of a factor analysis of mathematics and cross-curricular problem solving items from PISA 2003 (OECD, 2004b, Chapter 3), indicating correlated but distinct factors for mathematics and cross-curricular problem solving.[2]

1.2. Cognitive potential exploitation hypothesis

Against the background described in Section 1.1, PISA 2003 showed unexpected results for Germany (Leutner et al., 2004; OECD, 2004b): Whereas students in Germany obtained results above the average in cross-curricular problem solving ($M = 513$, SD = 95) compared with the OECD mean of 500 (SD = 100), they performed only averagely in mathematics ($M = 503$, SD = 103), science ($M = 502$, SD = 111), and reading ($M = 491$, SD = 109).[3] This difference between students' cross-curricular problem solving competence and their subject-specific competences, for example in mathematics, can be interpreted in terms of a 'cognitive potential exploitation hypothesis' (OECD, 2004b; see also Leutner et al., 2004): Cross-curricular problem solving and mathematical problem solving are very similar on a conceptual level (OECD, 2004b, see Section 1.1) and on an

[1] Preliminary results based on a subsample (complete cases only) are published in short form in Buchwald, Fleischer, Rumann, Wirth, and Leutner (in press). In the present paper we extend the theoretical elaboration (e.g., distinction of analytical and complex problem-solving, description of components of problem-solving), report analyses based on multiple imputation in order to account for missing data, and discuss limitations and future research in greater detail.

[2] For another discussion concerning the validity and dimensionality of the PISA assessment see Rindermann (2006) and the reply by Baumert, Brunner, Lüdtke, and Trautwein (2007).

[3] Please note that (1) all PISA tests are scaled on an international metric with a mean of 500 and a standard deviation of 100 across all participating OECD countries and (2) that the results do not mean that the absolute performance in problem-solving is higher than in the subject-specific domains.