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Effects of collaboration scripts and heuristic worked examples on the acquisition of mathematical argumentation skills of teacher students with different levels of prior achievement☆

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ABSTRACT

A challenging demand for mathematics teacher students is to produce acceptable scientific mathematical argumentations. We investigated to what extent mathematics teacher students with different levels of prior achievement who collaborated in dyads can be supported in their development of mathematical argumentation skills by two different instructional approaches that were systematically varied in a 2 × 2-factorial design: collaboration scripts (with vs. without) and heuristic worked examples vs. problem solving. An experimental study was run in the context of a two-weeks preparatory course for beginning mathematics teacher students ($N = 101$). Mathematical argumentation skills were conceptualized as consisting of an individual-mathematical and a social-discursive component. Results indicated positive effects of both scaffolds on the social-discursive component. Moreover, the effects of both scaffolds on both components were dependent on learners' prior achievement (high-school GPA). Heuristic worked examples and collaboration scripts were particularly effective in the facilitation of mathematical argumentation skills for teacher students with higher general learning prerequisites. Possible process-based explanations for this pattern of results as well as ways to more specifically address the needs of teacher students with lower prior achievement are discussed.

1. Introduction

The ability to construct arguments for and against mathematical claims and to generate or inquire mathematical conjectures has shifted into the focus of mathematics curricula worldwide during the last decade (e.g., National Governors Association Center for Best Practices, 2010). Mathematics teachers are thus demanded to help students acquire skills and competences related to mathematical argumentation. However, upon entering university education, many teacher students do not have the corresponding skills at their disposal to a sufficient extent. In other words, their capability to master mathematical argumentation varies with their overall *prior achievement*, that is with differences in the GPA they achieved at high school (e.g., Blömeke, Suhl, Kaiser, & Döhrmann, 2012). Since conveying mathematical argumentation skills (MAS) to mathematics teacher students is an important educational goal, it requires exploration about how to support them in the acquisition of MAS. Given the diversity of mathematics teacher students' learning prerequisites, it is also important to know to what extent instruction must to be tailored to the needs of students with lower vs. higher prior achievement.

We conceptualize MAS as the ability to inquire mathematical conjectures individually or in collaborative contexts, finally arriving at a proof or refutation for the conjecture (e.g., Koedinger, 1998). We propose to distinguish at least two components of MAS: a domain-specific, *individual-mathematical* and a domain-general, *social-discursive* component. The individual-mathematical component refers to the individual ability to generate arguments for or against a mathematical conjecture, to evaluate these arguments according to mathematical criteria, and to select and combine these arguments for a mathematical proof or refutation (Heintz, 2000;

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Reichersdorfer et al., 2012). The social-discursive component refers to the ability to participate in collaborative argumentation processes in social situations (Kollar, Fischer, & Slotta, 2007). Of course, expertise in MAS also includes domain-specific, social-discursive practices and skills (e.g., Yackel & Cobb, 1996) such as checking each others' arguments according to mathematical standards, which are at the interface of the two components described above. The current study was interested in contrasting domain-general and domain-specific aspects of MAS and will thus focus only on *individual-mathematical* and *social-discursive* aspects.

Over the past decade, a lot of research has investigated the effects of scaffolds directed at helping learners acquire social-discursive argumentation skills, especially in the context of Computer-Supported Collaborative Learning (CSCL). There, the collaboration script approach (e.g., Dillenbourg & Jermann, 2007; Fischer, Kollar, Stegmann, & Wecker, 2013) has been shown to be particularly effective (e.g., Noroozi, Weinberger, Biemans, Mulder, & Chirazi, 2013; Rummel & Spada, 2005; Scheuer, McLaren, Weinberger, & Niebuhr, 2013; Stegmann, Wecker, Weinberger, & Fischer, 2012; Wecker & Fischer, 2011). While such scripts have typically been effective in fostering social-discursive aspects of argumentation skills, they rarely had additional positive effects on domain-specific learning outcomes. If MAS are considered as including both a social-discursive and an individual-mathematical component, it therefore seems promising to combine the presentation of collaboration scripts with domain-specific scaffolding techniques. This, however, has hardly been investigated systematically in prior research, especially in mathematics.

One candidate for fostering the individual component of MAS are heuristic worked examples (e.g., Atkinson, Catrambone, & Merrill, 2003; Paas & van Merriënboer, 1994; Schwonke et al., 2009). In a study that aimed at fostering MAS in grade 8 students, Hilbert, Renkl, Kessler, and Reiss (2008) showed that studying heuristic worked examples was more effective than studying an instructional text on geometry to foster conceptual knowledge on mathematical argumentation and individual MAS. However, although heuristic worked examples have already been used to support small groups of learners (Reiss, Heinze, Kessler, Rudolph-Albert, & Renkl, 2007), their effectiveness should be amplified when scaffolds that particularly aim at an improvement of social-discursive aspects of their argumentation support collaborative example elaboration.

This article reports an empirical study with mathematics teacher students at the start of their university education. The study investigated whether heuristic worked examples can successfully be combined with computer-supported collaboration scripts to foster students' MAS, with a particular focus on whether teacher students with different levels of prior achievement benefit equally from these two interventions.

1.1. The role of prior achievement as an individual learning prerequisite

Teacher students typically start academic education shortly after their secondary school degree, and there is considerable variance in their prior achievement, that is in their high-school GPAs (Blömeke et al., 2012). Based on a meta-analysis of more than 800 studies to identify the main variables that affect later achievement, Hattie (2009) found prior achievement to be among the most influential predictors, with an average effect size of $d = .67$ (for the transition from high school to university, see Kuncel, Hezlett, & Ones, 2001). In research on Aptitude–Treatment-Interactions (ATI), this phenomenon is often interpreted as a "Matthew effect" meaning that students with higher prior achievement benefit more from a given kind of instruction than learners with lower prior achievement (see Stanovich, 1986). This can be explained by the assumption that prior achievement goes along with the level of prior knowledge a student has accumulated. Students with higher levels of prior knowledge have a higher chance to identify relevant information (Alexander & Jetton, 2003), to connect this information to existing schemata, and to integrate new information more easily into their existing knowledge structures in long-term memory. Even more detailed predictions can be derived from the Construction-Integration Model (Kintsch, 1998). As Scheiter and Gerjets (2007) point out, learners with low prior knowledge require instructional texts that present the micro- and macro-structure of a text very clearly. High prior knowledge students, in contrast, tend to benefit from less coherent texts. Nevertheless, Barab, Bowdish, and Lawless (1997) argue that this prediction is restricted to learning tasks which require text comprehension and that dependence on prior knowledge should be less pronounced for tasks which require independent information processing and problem solving. In summary, these lines of reasoning lead to the hypothesis that the advantage of students with higher levels of prior achievement compared to learners with lower levels of prior achievement (Matthew effect) will be more pronounced when the learning environment requires to extract and integrate information from texts compared to environments that rely less on text comprehension. Applied to learning from heuristic worked examples and collaboration scripts, which both are typically presented in a textual format (Kollar et al., 2007; Reiss & Renkl, 2002), it may thus be expected that learners with higher prior achievement will be in an advantageous position compared to learners with lower prior achievement.

However, research on the "expertise-reversal effect" (Kalyuga, Rikers, & Paas, 2012) seems to suggest the contrary: For example, Rey and Buchwald (2011) have shown that more structured scaffolds (in their case a combination of text and animations that was presented to learners who were supposed to acquire knowledge on a mathematical optimization algorithm) were particularly effective for students with lower rather than high levels of prior knowledge. Learners with higher prior knowledge were better off when they were only presented with text (and no animation). The usual interpretation for such an effect is that if a learner already has the knowledge necessary to solve a certain type of tasks, information provided in a scaffold becomes redundant and produces extraneous load (Sweller, 2010) which is negatively related to knowledge acquisition. This line of reasoning would predict a negative influence of high prior knowledge on learning gain in learning environments with scaffolds that are textually represented, which is typical for worked examples and collaboration scripts.

Transferred to our study, it seems unclear what role prior achievement will play when students are provided with scaffolds targeting MAS: The Matthew effect argumentation predicts that providing students with collaboration scripts and heuristic worked examples will be especially beneficial for students with higher levels of prior achievement. Yet, the expertise-reversal position would predict the contrary. It should be noted that in research on the Matthew effect often quite general learning prerequisites like prior school achievement are considered. In contrast, more specific prior skills are usually considered in the worked example research tradition.

1.2. Facilitating MAS with collaboration scripts

The social-discursive component of MAS is necessary to communicate ideas and solutions for mathematical problems to others and to reach joint solutions based on group discussions. Collaborative learning is regarded a promising approach to foster the corresponding skills (e.g., Slavin, 1996). However, a wealth of