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How much is too much? Learning and motivation effects of adding instructional explanations to worked examples

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ABSTRACT

A central goal of the learning sciences is to discover principles that determine the optimal amount of instructional assistance to support robust learning (Koedinger & Aleven, 2007). We examined learning outcomes from providing and withholding stepwise instructional explanations as students studied worked examples and solved physics problems. We hypothesized that students would acquire more conceptual knowledge from withholding instructional explanations because they would be more likely to engage in constructive cognitive activities to understand the problem-solving steps, whereas providing instructional explanations might suppress such activities. Furthermore, we examined the roles of prior knowledge and student motivation in determining learning outcomes. Across three experiments, students in the withholding conditions showed greater conceptual learning than students in the providing conditions. Additionally, achievement goal orientations were more predictive of learning for the withholding conditions than the providing conditions. We discuss how the interactions between prior knowledge, motivation, and instruction can support learning and transfer.

1. Introduction

Instructors in every domain face a common challenge in determining when to provide students with explanations and when to have them generate their own. This challenge creates a pedagogical dilemma for choosing between the intuitive merits of two instructional approaches. On one hand, providing detailed examples and instructional explanations can help a learner obtain an accurate understanding of a topic in a relatively quick, efficient manner by focusing attention on appropriate solution paths and key features while discouraging the use of inefficient or inaccurate strategies. On the other hand, leaving a learner to figure out a problem on her own can promote constructive cognitive activities such as self-explanation, which can facilitate a deep understanding of the materials (Chi, Slotta, & de Leeuw, 1994; Renkl, 1997). Although the challenge of finding an appropriate level of instructional assistance arises in a number of learning situations, it is especially salient in the domains of math and science instruction, where common instructional approaches range from solving open-ended problems to studying highly scaffolded worked examples that incorporate instructional explanations.

The advantages and disadvantages of providing versus withholding information have been explored from a number of perspectives in the learning sciences, including research on desirable difficulties (Bjork, 1994; Schmidt & Bjork, 1992), worked examples (Renkl, Atkinson, & Maier, 2000), and the assistance dilemma in intelligent tutoring systems (Koedinger & Aleven, 2007). Recently, Wittwer and Renkl (2010) published a meta-analysis showing that providing instructional explanations in worked examples (i.e., explanations of either the principles or operators applied in accompanying worked examples) had a positive effect on the acquisition of conceptual knowledge, but not on problem-solving skills. However, the effects were found only in the domain of math, not in science or learning science disciplines, and they disappeared when compared to worked examples that encouraged self-explanation. These findings show that there are important moderating factors on the effectiveness of providing instructional explanations, and that there may be particular situations in which withholding such explanations would be beneficial for learning and transfer. To further investigate this issue, we compared learning outcomes from providing versus withholding instructional explanations as students studied worked examples and solved practice problems in electricity. To determine what was learned, we measured conceptual reasoning, problem-solving

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performance, and preparation for future learning. We also explored the role of two factors hypothesized to be particularly important for learning from withholding instructional explanations: the roles of *prior knowledge* and *achievement motivation*.

First, we tested the hypothesis that worked examples and problem-solving activities that withhold instructional explanations promote deeper conceptual learning than activities that provide explanations [Hypothesis 1, Experiments 1, 2, and 3]. Second, we examined whether such learning depends on knowing the relevant ontological categories for the to-be-learned science concepts [Hypothesis 2, Experiment 1]. Third, we tested the hypothesis that students' achievement orientations have a larger effect on learning outcomes when instructional explanations are withheld compared to when they are provided [Hypothesis 3, Experiments 1, 2, and 3]. We expected that withholding explanations would force students to rely more on their personal achievement motivations (e.g., strive for understanding or performance) to regulate their learning activities and behaviors. Furthermore, we examined the possibility that withholding instructional explanations might promote the adoption of mastery goals (i.e., the desire to understand) because the materials put more responsibility on the students to make sense of them, in contrast to telling the students what they needed to know [Hypothesis 4, Experiments 2 and 3].

In the sections that follow, we describe the cognitive and motivational processes that providing and withholding instructional explanations are hypothesized to support (Section 1). We then present three experiments that examine what is learned from withholding or providing instructional explanations in worked examples and problem-solving activities. We also examine the roles of prior knowledge and achievement orientations in that learning (Sections 2–4). We conclude with a discussion of the results and implications for instructional theory (Section 5).

1.1. Balancing withholding and providing information

The question of whether providing or withholding information in worked examples and problem-solving activities leads to better learning outcomes depends on a number of instructional factors including the nature of the information (problem-solving steps versus instructional explanations), the amount of information provided (a little or a lot), and when the information is provided or withheld (early or late in practice). Many experiments have examined a direct comparison of problem solving, an activity that provides little to moderate assistance depending on whether any help is given in addition to the problem, against worked example study, which provides more assistance by illustrating the solution steps and final answer to the problem. The results have generally favored the use of worked examples interleaved with practice problems over problem solving alone to support learning and transfer (e.g., Renkl et al., 2000; Renkl, Atkinson, Maier, & Staley, 2002; Ward & Sweller, 1990).

Providing worked examples along with practice problems improves learning and reduces memory load by eliminating the need for the learner to maintain too many pieces of knowledge in working memory at a given time and instead allowing her to utilize the information provided in the worked example (Paas & Van Merriënboer, 1994; Ward & Sweller, 1990). Additionally, worked examples can support more efficient learning by reducing the pursuit of incorrect solution paths and focusing the student on the correct problem steps. For example, within the context of an intelligent tutoring system, Mclaren, Lim, and Koedinger (2008) found that a group that solved problems with interleaved worked examples achieved mastery in significantly less time than a group that just solved problems.

Providing too much information, however, may come with a cost. Renkl et al. (2000) found that decreasing the amount of information provided across a series of worked examples – a process the authors called "fading" – improved performance on near-transfer problems (i.e., problems with a similar structure to the examples) compared to a condition that continued to receive complete worked examples throughout the sequence. The authors concluded that the process of generating the missing steps gave students in the fading condition a learning advantage. These results suggest that providing some information is fruitful, but withholding information at critical junctures may also facilitate constructive cognitive processes that improve learning and transfer.

In addition to providing or withholding worked examples or steps of worked examples, researchers have also examined providing instructional explanations within worked examples. Instructional explanations typically consist of definitions of the key concepts and principles used in the examples as well as descriptions of the relationships between those concepts (Leinhardt, 2010; Renkl, 2002; Wittwer & Renkl, 2008). They can also include descriptions of the links between goals and operators as well as the application conditions for using those operators (Wittwer & Renkl, 2010; van Gog, Paas, & van Merriënboer, 2008). Given that not all instructional explanations are productive, much recent work has gone into determining what makes instructional explanations effective, both in classroom dialog and in written materials (Leinhardt, 2001; Renkl, 2002; Schworm & Renkl, 2006; Wittwer & Renkl, 2008, 2010). For example, Wittwer and Renkl (2008) reviewed the instructional explanations literature in an effort to identify the key characteristics of explanations that support robust learning. They argued that instructional explanations should be adapted to learners' prior knowledge, focused on principles or conceptual information, and designed to engage learners in constructing or applying knowledge. We used these recommendations to guide the development of the instructional explanations tested in the current studies.

1.2. Effects of inference generation

Evidence from worked example experiments (e.g., Renkl, 1997; Renkl et al., 2000) suggests that inference generation might be the key cognitive process driving benefits of withholding information. To test this hypothesis, Hausmann and VanLehn (2007) compared the learning outcomes of students who were instructed to self-explain worked examples (i.e., engaging in inference generation) to students who were asked to paraphrase those same examples (i.e., suppressing inference generation). Regardless of whether the worked examples were complete or incomplete, the students who self-explained performed with greater accuracy on the learning materials and on both near- and far-transfer homework problems (i.e., problems that had either similar or different structures compared to the learning problems). The results suggest the self-explanation prompts triggered inference generation, which supported greater learning gains than simply paying attention to the provided instructional explanations. Consistent with these findings, Schworm and Renkl (2006) found that self-explanation prompts improved math teachers' learning outcomes, while providing them with instructional explanations reduced spontaneous self-explanations and, in turn, negatively affected their learning. These results indicate that it is not simply the type of information provided in the worked examples that is important but also *how* that information is processed (inference generation or paraphrasing). It suggests that students may benefit from materials that encourage them to self-explain, even if they are not able to generate high-quality explanations.