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The worked-example effect: Not an artefact of lousy control conditions

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ABSTRACT

Recently it has been argued that the worked-example effect, as postulated by Cognitive Load Theory, might only occur when compared to unsupported problem-solving, but not when compared to well-supported or tutored problem-solving as instantiated, for example, in Cognitive Tutors. In two experiments, we compared a standard Cognitive Tutor with a version that was enriched with faded worked examples. In Experiment 1, students in the example condition needed less learning time to acquire a comparable amount of procedural skills and conceptual understanding. In Experiment 2, the efficiency advantage was replicated. In addition, students in the example condition acquired a deeper conceptual understanding. The present findings demonstrate that the worked-example effect is indeed robust and can be found even when compared to well-supported learning by problem-solving.

1. Introduction

The worked-example effect postulated within *Cognitive Load Theory* (CLT) states that in initial cognitive skill acquisition it is more favorable to learn from examples with worked solutions than to solve problems. More specifically, it has been found that the usual procedure of learning by problem-solving (i.e., introducing a topic, presenting one worked example, and then providing problems to-be-solved) is less effective as prolonging the phase of example study and only then to move to problem-solving (e.g., Atkinson, Derry, Renkl, & Wortham, 2000; Paas & van Gog, 2006; Sweller & Cooper, 1985).

Recently, however, Koedinger and Aleven (2007) as well as McLaren, Lim, Gagnon, Yaron, and Koedinger (2006) have argued that the superiority of learning from examples might be due to the fact that former studies have compared this learning method only with unsupported problem-solving (Mwangi & Sweller, 1998; Zhu & Simon, 1987). McLaren et al., for example, interspersed problem-solving activities within a Cognitive Tutor for chemistry with worked examples and did not find an advantage of the example enriched environment. The result was replicated both with high school students and college students. The authors argued that prior research, in contrast to their studies, did usually not involve (immediate) feedback, which is, however, important to keep students from pursuing unproductive paths. In terms of CLT, unsupported problem-solving can pose heavy *extraneous load* on the students because it is characterized by errors and unproductive search procedures (Sweller, Van Merriënboer, & Paas, 1998). Extraneous load refers to load imposed on a learner's working memory by instructional design that requires to engage in activities that do not contribute to learning (Sweller, 1994). Tutored problem-solving may significantly relief students from this load. Therefore, McLaren et al. raise the possibility that there might be no superiority of learning from examples when compared to supported or tutored problem-solving as instantiated, for example, in Cognitive Tutors.

Cognitive Tutors – as a state-of-the-art implementation of tutored problem-solving – have been proven to be effective in supporting students' learning in a variety of domains such as mathematics, computer programming, and genetics (for an overview, see Anderson, Corbett, Koedinger, & Pelletier, 1995; Koedinger & Corbett, 2006). On the basis of online assessments of the student's learning behavior, the tutors provide individualized support for guided learning by problem-solving. Specifically, they select appropriate problems, give just-in-time feedback, and present hints. Despite their effectiveness, however, one limitation of these tutors is that they primarily focus on students' problem-solving skills and do not necessarily support deeper conceptual understanding (see Wirth, Künsting, & Leutner, 2009, for effects of problem-solving goals vs. learning goals on cognitive load and learning outcomes). However, as the iterative model by Rittle-Johnson and Siegler (1998) suggests, both procedural skills and conceptual understanding are important for further knowledge acquisition; advances in conceptual understanding supports procedural skills and vice versa. Aleven and Koedinger (2002) addressed this limitation of Cognitive Tutors by adding self-explanation prompts to the tutor. The prompts require students to provide

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an explanation for each solution step by making explicit references to the underlying principle. In this way, tutored problem-solving may not only reduce extraneous load but also induce *germane-load*. Germane-load refers to load on working memory that is related to learning (Sweller, 1994). Aleven and Koedinger found that that this instructional procedure makes the Cognitive Tutor indeed more effective.

However, from a cognitive load perspective (e.g., Sweller et al., 1998), it can be argued that learning by problem-solving and self-explaining in Cognitive Tutors is nevertheless suboptimal. The induction of self-explanation activities in addition to problem-solving puts fairly high demands on students' limited cognitive capacity, particularly in the early stages of skill acquisition (see Kalyuga, in press). Therefore, the tutors might be further improved by reducing extraneous cognitive load in these early phases (e.g., Van Merriënboer, Kirschner, & Kester, 2003). In other words, relieving students from any problem-solving demands in the first place allows them to direct their full processing capacities at developing a basic understanding of the domain principles *before* any attempts to solve problems.

Against this background, it should be favorable to provide worked examples. The instructional model of example-based learning by Renkl and Atkinson (2007) suggests that students gain a deeper understanding of domain principles when they receive worked examples at the beginning of cognitive skill acquisition. A worked example consists of a problem formulation, solution steps, and the final solution. Increasing the chances that students have a basic understanding of the principles before they start to solve problems should help them to deal with the problem-solving demands by referring to already acquired principles, which should prevent them from using only shallow strategies such as means-end analysis or copy-and-adapt strategies (i.e., using the solution of a previously solved problem that is adapted with respect to the specific numbers). Although these strategies are not shallow per se, in the early stages of skill acquisition when understanding is still low, they can only rely on superficial problem features and are thus superficial strategies. The use of principles on the other hand enables students to deepen their understanding by applying the principles to new problems and, in addition, help them to notice gaps in their principle-related understanding when reaching an impasse (see VanLehn et al., 2005).

There is ample empirical evidence showing that learning from worked examples leads to superior learning outcomes as compared to problem-solving (see, e.g., Atkinson et al., 2000; Hilbert & Renkl, 2009). However, it is important to note that studying worked examples lose their effectiveness with increasing expertise (cf. *expertise reversal effect*; Kalyuga, Ayres, Chandler, & Sweller, 2003). With growing skills the instructional goals change (cf. the three-stage model of skill acquisition by VanLehn, 1996). In later stages of skill acquisition, the execution of problem-solving activities plays a more important role because emphasis is put on increasing speed and accuracy of performance (Renkl & Atkinson, 2003). Accordingly, Kalyuga, Chandler, Tuovinen, and Sweller (2001) found that learning from worked examples was superior in the initial phase of cognitive skill acquisition. When students, however, already had a basic understanding of relevant principles of a domain, solving problems proved to be more effective than studying examples. When the sub-components of the skill should be automated in later learning stages, self-explanations are not very helpful and solving problems or parts of them becomes a germane-load activity because it fosters automation.

Against this background, Renkl and Atkinson (2003) proposed a fading procedure in which problem-solving elements are successively integrated into example study until the students solve problems on their own. After presenting a complete example first, structurally identical but increasingly incomplete examples are provided. In each of these examples only one step is omitted until just the problem formulation is left (i.e., a problem to be solved). By gradually increasing problem-solving demands, the students should retain sufficient cognitive capacity to focus on understanding the domain principles. Such an instructional procedure is also compatible with the employment of a completion (teaching) strategy as recommended by the 4C/ID theory by Van Merriënboer and colleagues (Paas, 1992; Van Merriënboer, Clark, & De Croock, 2002). This strategy involves a transition form worked examples, via completion problems, to problem-solving (Van Merriënboer, 1997) that strongly resembles the present fading strategy. In a number of experiments, Renkl and colleagues provided empirical evidence for the effectiveness of such smooth transitions from example study to problem-solving (e.g., Atkinson, Renkl, & Merrill, 2003; see also Kalyuga & Sweller, 2004).

Given the effectiveness of learning from faded worked examples, we assumed that the Cognitive Tutors can be improved further by implementing faded worked examples. Thus, a combination of gradually faded worked examples and tutored problem-solving in contrast to tutored problem-solving alone should make the tutor more effective in fostering students' learning, particularly with respect to their conceptual understanding. The empirical results on the *worked-example effect*, that is, the positive effect of studying examples, have also shown that students usually need less study time (see e.g., Paas & Van Merriënboer, 1994). Accordingly, we hypothesized that the example-enriched tutored problem-solving would be more effective and more efficient than tutored problem-solving alone. In order to test these hypotheses, we modified a Cognitive Tutor lesson on geometry by integrating a state-of-the-art implementation of example-based learning with a gradual transition into problem-solving.

In this article, we present two experiments. In Experiment 1, students were to acquire and apply a set of geometry principles with these two instructional approaches, (implemented in two versions of a Cognitive Tutor lesson). As main outcome measures, we considered procedural skills and conceptual understanding because both types of knowledge are important for further knowledge acquisition. In addition, we took the required learning time into account. In Experiment 2, we replicated and complemented the findings of the first experiment on outcome measures by learning process measures from think-aloud protocols.

2. Experiment 1

2.1. Method

2.1.1. Sample and design

Fifty students from a German high school, 22 eighth grade students and 28 ninth grade students, participated in the experiment (age: $M = 14.3$ years, $SD = .70$; 22 females, 28 males). The students were randomly assigned to one of two experimental conditions. Students from different grade levels were distributed equally across conditions ($\chi^2 = 0$; $p > .99$). In the experimental condition (in the following labeled *example condition*; $n = 25$), students worked in a computer-based tutored problem-solving environment that presented faded worked examples. In the control condition (in the following labeled *problem condition*; $n = 25$), the students worked in a tutored problem-solving environment in which students had to determine all solution steps on their own, as in the traditional Cognitive Tutor.

2.1.2. Learning environment – The Cognitive Tutor

Dependent on the condition, the students used two versions of the Geometry Cognitive Tutor, which differed by a single factor: whether or not worked examples were presented. The Cognitive Tutor is a state-of-the-art intelligent tutoring system that is