Computers in Human Behavior 55 (2016) 87–99

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Full length article

# The efficiency of worked examples compared to erroneous examples, tutored problem solving, and problem solving in computer-based learning environments

Bruce M. McLaren [a, 1, *], Tamara van Gog [b, c, 1], Craig Ganoe [a], Michael Karabinos [d], David Yaron [d]

[a] Human-Computer Interaction Institute, Carnegie Mellon University, Pittsburgh, USA
[b] Department of Pedagogical and Educational Sciences—Education, Utrecht University, The Netherlands
[c] Institute of Psychology, Erasmus University Rotterdam, The Netherlands
[d] Chemistry Department, Carnegie Mellon University, Pittsburgh, USA

ARTICLE INFO

*Article history:*
Received 1 June 2015
Received in revised form
19 August 2015
Accepted 24 August 2015
Available online 14 September 2015

*Keywords:*
Worked examples
Erroneous examples
Conventional problem solving
Intelligent tutoring

ABSTRACT

How much instructional assistance to provide to students as they learn, and what kind of assistance to provide, is a much-debated problem in research on learning and instruction. This study presents two multi-session classroom experiments in the domain of chemistry, comparing the effectiveness and efficiency of three high-assistance (worked examples, tutored problems, and erroneous examples) and one low-assistance (untutored problem solving) instructional approach, with error feedback consisting of either elaborate worked examples (Experiment 1) or basic correctness feedback (Experiment 2). Neither experiment showed differences in learning outcomes among conditions, but both showed clear efficiency benefits of worked example study: equal levels of test performance were achieved with significantly less investment of time and effort during learning. Interestingly for both theory and practice, the time efficiency benefit was substantial: worked example study required 46–68% less time in Experiment 1 and 48–69% in Experiment 2 than the other instructional approaches.



## 1. Introduction

A major and recurring question for teachers and developers of instructional software is how much guidance or assistance they should provide in order to lead to the best learning outcomes for students (see debates and research on high versus low or 'minimal' guidance instruction: e.g., Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Hmelo-Silver, Duncan, & Chinn, 2007; Kapur & Rummel, 2012; Kirschner, Sweller, & Clark, 2006; Mayer, 2004; Schmidt, Loyens, van Gog, & Paas, 2007; Tobias & Duffy, 2009; Wijnia, Loyens, Van Gog, Derous, & Schmidt, 2014). On the one hand, some educational researchers conjecture that too much instructional assistance can lead to lower learning outcomes and feelings of boredom and demotivation, as students have little to do on their own. On the other hand, other researchers have argued that too little assistance may lead to lower learning outcomes or inefficient and frustrating learning processes when students do not know what to do. The decision of how much assistance to provide students learning with instructional software, balancing between making instructional materials supportive and challenging, has been called the 'assistance dilemma' (Koedinger & Aleven, 2007). When it comes to teaching problem-solving skills, for instance, worked examples are on the high guidance side of the assistance continuum. Worked examples present students with a fully worked-out problem solution to study and (possibly) explain. On the low (or rather: no) guidance side of the continuum are problems that students attempt to solve themselves without any instructional guidance whatsoever.

It is well-established that for novices, studying *worked examples only* (Nievelstein, Van Gog, Van Dijck, & Boshuizen, 2013; Van Gerven, Paas, Van Merriënboer, & Schmidt, 2002; Van Gog, Paas, & Van Merriënboer, 2006) or *example-problem pairs* (Carroll, 1994; Cooper & Sweller, 1987; Kalyuga, Chandler, Tuovinen, & Sweller, 2001; Mwangi & Sweller, 1998; Rourke & Sweller, 2009; Sweller & Cooper, 1985) is generally *more effective* for learning and transfer than practicing conventional problem solving (i.e.,

* Corresponding author. Human-Computer Interaction Institute, 5000 Forbes Avenue, Carnegie Mellon University, Pittsburgh, PA, 15213-3891 United States.
*E-mail address:* bmclaren@cs.cmu.edu (B.M. McLaren).
[1] First two authors should be considered as first author.

http://dx.doi.org/10.1016/j.chb.2015.08.038
0747-5632/

without any assistance). Moreover, worked examples or example–problem pairs have also been shown to be *more efficient* than conventional problem solving, in the sense that equal or higher test performance is reached in less study time and with less investment of mental effort (an indicator of cognitive load). This has become known as the 'worked example effect' (for reviews, see Atkinson, Derry, Renkl, & Wortham, 2000; Clark & Mayer, 2011; Renkl, 2014a, 2014b; Sweller, Ayres, & Kalyuga, 2011; Sweller, Van Merriënboer, & Paas, 1998; Van Gog & Rummel, 2010).

The efficiency of studying worked examples compared to problem solving makes sense when one looks at the cognitive processes involved. When novices, who lack knowledge of effective problem-solving procedures, have to practice solving problems without any assistance or instructional guidance, they are forced to resort to weak problem-solving strategies, such as means-ends analysis (Simon, 1981), in which learners search for operators to reduce the difference between the current problem state and the goal state (Sweller, 1988). This takes a lot of time and imposes a high load on working memory (i.e., is effortful) but is not effective for learning, that is, for building a cognitive schema of how such problems should be solved (Sweller, 1988; Sweller & Levine, 1982). Consequently, when learners are presented with a subsequent, similar practice problem, they again have to rely on the same, inefficient strategies. When studying worked examples, in contrast, learners do not have to spend time and effort on weak problem-solving strategies, but instead, can devote all of their attention to learning how such problems should be solved, that is, to constructing a cognitive schema that can guide future problem solving when instructional assistance is no longer available.

Worked example study, however, has been criticized as a relatively 'passive' form of instruction. Even though the cognitive schema of the solution procedure has to be actively constructed by a learner, it is constructed based on example study rather than production or generation of problem-solving steps. It has been argued that there is a benefit to sometimes withholding assistance in favor of having learners actively produce or generate solutions (Koedinger & Aleven, 2007). Koedinger and Aleven even suggest that it is unlikely that instruction consisting of only studying worked examples would be better than interleaving worked examples and problem solving (i.e., in which the learner studies *and* engages in problem solving), although they added, "We do not know of such a direct comparison …" (p. 243).

Indeed, in 2007, when their article appeared, no such direct comparisons had been conducted yet. More recent studies, however, have shown that there were no differences in learning outcomes or effort investment between examples only and example–problem pairs and that both were more effective than conventional problem solving only on an immediate test (Leppink, Paas, Van Gog, Van der Vleuten, & Van Merriënboer, 2014; Van Gog, Kester, & Paas, 2011). One might argue in light of research on the testing effect, though, that the benefits of alternating example study with problem solving would only arise on a delayed test. That is, research has shown that after initial study, testing is more effective for long-term learning than restudying, even though on an immediate test there may be no differences or restudy might even be more effective (Roediger & Karpicke, 2006; Rowland, 2014). Given that example–problem pairs resemble a study-test situation whereas example study only resembles restudy, one might expect that example–problem pairs would lead to better performance on a delayed test. However, several studies have shown that this is not the case, and example–problem pairs and example study are equally effective even when learning outcomes are measured one week later (Leahy, Hanham, & Sweller, 2015; Van Gog & Kester, 2012; Van Gog et al., 2015; potentially, this finding can be explained by the complexity of the learning material; see Van Gog & Sweller, 2015).

So in contrast to the suggestion that it is sometimes better to withhold assistance (Koedinger & Aleven, 2007), these findings suggest that giving novice learners full support (i.e., only having them study examples), is neither better nor worse for learning than first providing and then withholding support (i.e. example–problem pairs). However, it should be noted that the above studies were single-session experiments, conducted either in a lab setting or in a single classroom period, involving relatively short sequences of learning tasks. In other words, ecological validity was low and it cannot be ruled out that withholding assistance would have beneficial effects in real classroom settings. Yet, in at least one classroom study, conducted over a period of up to 6 class periods, McLaren and Isotani (2011) found that a condition consisting of only worked examples led to students learning just as much, in significantly less time, than both an alternating examples/tutored problems condition and an all tutored problems condition. This study was different from the aforementioned lab studies in that the worked examples contained some "active" elements (i.e., answering self-explanation questions after viewing worked example videos). Nevertheless, this study provides further evidence that exclusively studying worked examples may be more efficient – although not necessarily more effective – for learning than has been assumed.

Moreover, the McLaren and Isotani (2011) study is important because the effectiveness of worked examples was not compared to "conventional" problem solving, but rather to another 'high assistance' condition, namely tutored problems in which students are supported by hints and feedback on each step when needed. Koedinger and Aleven (2007) have suggested that the worked example effect arises mainly because no guidance whatsoever is given in conventional problem solving: "In the context of tutored practice as opposed to untutored practice, the information-giving benefits of worked examples may essentially be redundant. In essence, the tutor dynamically converts a problem-solving experience into an annotated worked example when the student is having enough trouble such that they request the final 'bottom-out' level of hint that tells them what to do next". (p. 257).

Koedinger and Aleven (2007) subsequently initiated several studies to investigate this assumption, and found instead that interleaving example study and tutored problem solving proved to be more efficient than tutored problem solving alone (McLaren, Lim, & Koedinger, 2008) and that faded examples with increasingly more steps for the learner to complete with tutor support were more efficient than tutored problem solving alone (Schwonke et al., 2009; for a review of effects of [faded] worked examples in tutoring systems, see Salden, Koedinger, Renkl, Aleven, & McLaren, 2010). The McLaren and Isotani (2011) study goes beyond the prior studies by comparing worked examples only to interleaved example-tutored problem pairs and tutored problems only. Their data show that if students did use the tutored problems to "dynamically convert problem-solving experience(s) into annotated worked example(s)" in this study, it did not help them learn more or learn more efficiently.

This lack of learning benefit might be explained as follows. Whereas it is true that a tutored problem can essentially amount to a worked example when the student gets to the bottom-out hints, getting there is an inefficient process. It is likely to take much more time and effort to work through to the bottom-out hints of many individual problem solving steps than to study a full example. It is questionable whether this is time and effort well spent (especially for low prior knowledge learners), that is, whether it would contribute much to learning compared to studying a fully worked-out solution presented as a whole. Instead, why not give learners an example of a correct solution procedure immediately, rather than