

Worked Examples and the Assistance Dilemma

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It has long been noted that the balance between giving and withholding information exerts a major influence on students' learning. Koedinger and Aleven (2007) dub this issue "the Assistance Dilemma" and call for theory that will enable us to predict (1) how much assistance initially to provide to learners, as well as (2) when and how fast to fade it. A key manifestation of the Assistance Dilemma is the choice between worked-examples (high assistance) and problems (lower assistance). This issue has been well-researched in the context of non-interactive learning environments; we address it in the context of (highly interactive) Cognitive Tutors. We found that worked-examples enhance tutored problem solving, especially when the examples are adaptively faded based on individual students' learning. We are working toward a more principled way of transitioning from higher-assistance to lower-assistance forms of instruction.

Recently, Koedinger and Aleven (2007) pointed to a long-recognized fundamental problem in the learning sciences, which they dubbed the Assistance Dilemma: if the balance between *giving* information (or assistance) to students and *withholding* it exerts a major influence on students' learning, how do we decide where the optimal balance point is? The Assistance Dilemma applies to a wide range of instructional phenomena, including spacing of practice tasks (Koedinger, Pavlik, McLaren, & Aleven, submitted), provision of (step-by-step) feedback during problem-solving practice, availability and content of on-demand hints provided by the (interactive) learning environment, etc. When is it productive to provide these (and other) forms of assistance, and when is it productive to withhold them, and let the learner generate or construct solutions themselves? In general, giving more assistance is very likely to reduce unproductive floundering and concomitant frustration, but it is quite possible that the learning benefits of given information may be lower than the learning benefits of information that the student generated for themselves. Then again, with less assistance, the likelihood of the students' succeeding in generating correct information may be lower (Koedinger & Aleven, 2007), meaning that less assistance may be detrimental. At this point in time, there is no theory that is sufficiently detailed to guide us in selecting optimal levels of assistance in a particular instructional situation, or even, with respect to a single dimension of assistance (but see Koedinger et al., submitted).

In this paper, we present our research findings related to a key manifestation of the Assistance Dilemma, namely, the choice between worked-out examples and problems. An extensive amount of research on worked-out examples exists (e.g., Sweller & Cooper, 1985; Trafton & Reiser, 1993), and it shows consistently that incorporating worked-out examples as a

supplement to problem-solving practice leads to beneficial learning effects. Worked examples are effective because more of the learners' limited processing capacity (i.e., working memory capacity) can be devoted to understanding the domain principles and their application in problem solving. As a result, subsequent problem solving will be guided by strong declarative knowledge of the problem-solving principles to be used, and students are less likely to use shallow problem-solving strategies. Prior research has found also that as learners progress through training, worked-out examples are not as effective in later stages of the training, a phenomenon often referred to as "the expertise reversal effect" (Kalyuga, Ayres, Chandler, & Sweller, 2003). It follows that worked-out steps should be presented early on yet when the learner demonstrates understanding, the worked-out steps should gradually be 'faded' meaning that the problems contain more and more open steps for which the learner must find the solution (Atkinson, Renkl, & Merrill, 2003; Renkl & Atkinson, 2007; Renkl, Atkinson, & Große, 2004; Renkl, Atkinson, Maier, & Staley, 2002).

Worked examples provide a key illustration of the Assistance Dilemma: they represent a higher level of assistance than giving students a problem to solve. In a worked-out example, information is provided that in pure problem solving, the learner is asked to generate. Thus, the transition from worked examples to problems can be viewed as a transition from higher assistance to lower assistance, and the many schemes for fading examples that have been reported in the literature can be viewed as different ways of deciding when and how to fade assistance in an attempt to optimize learning. Interestingly, until now we had no good way to address that question for individual learners: The expertise reversal effect suggests that the level of assistance should be reduced (by switching from problems to examples) as the students' knowledge acquisition increases. However, it does not give us specific suggestions on *when* and *how fast* to fade it. As it stands, the Assistance Dilemma is indeed a dilemma.

We investigate the examples/problems transition in the context of *interactive* learning environments, where until now it has received relatively little attention from learning sciences researchers. Most of the research discussed above has focused on examples as a supplement to problem solving with little or no assistance, as opposed to *tutored* problem solving. Further, we investigate how we can fade examples in a manner that is adaptive to individual learners' learning trajectories, and whether such adaptive fading leads to better learning than a one-size-fits-all approach. Thus, we address two key questions related to examples/problems manifestation of the Assistance Dilemma: (1) how much assistance to provide initially – is the added assistance that examples provide effective? (2) when and how to fade the assistance that examples provide.

As test bed for our work, we use Cognitive Tutors, a particular form of intelligent tutoring systems, grounded in cognitive theory that support practice of complex problem-solving skill. Cognitive Tutors individualize instruction by selecting problems based on a model of the students' knowledge state that is constantly being updated (Corbett & Anderson, 1995; Koedinger & Alevan, 2007). Cognitive Tutors give step-by-step feedback on students' problem-solving actions, and at any time students can request hints for a step they are having difficulty with. For each step of a problem, multiple hint levels are available that typically explain, as succinctly as possible, which problem-solving principle applies and how it can be used to solve the step. Typically, the final hint in each hint sequence provides the answer (i.e., the bottom out

hint). Because of the existence of the bottom-out hints, one can view this type of tutored problem solving as giving students worked-out steps upon their own request. The analogy with worked-examples is reasonable but not perfect: in Cognitive Tutors, an open problem step is turned into a worked-out step typically only after a learner's unsuccessful attempt at solving it since hint requests that precede an attempt at solving a step are less frequent than hint requests that follow errors. In addition, for an open step to become worked-out the learners have to recognize their need for help which typically is a challenging determination to make (see e.g., Alevan, McLaren, Roll, & Koedinger, 2006; Alevan, Stahl, Schworm, Fischer, & Wallace, 2003). Thus, it is an interesting question whether worked examples are synergistic with the "tutored problem solving" approach of Cognitive Tutors.

In two lab experiments, we found evidence that tutored problem solving combined with examples that were gradually faded has beneficial learning effects over tutored problem solving without worked examples (Schwonke et al., 2007). More specifically, the example enhanced Cognitive Tutor was less time consuming with no loss in terms of performance and consequently was more efficient than the standard Cognitive Tutor. Thus, adding examples leads to greater learning, even in the context of tutored problem solving. A higher initial assistance level was proven to be beneficial in this particular context. Additionally, a recent review of the worked-out example literature by McLaren, Lim, & Koedinger (submitted) suggested that *mid-level* assistance (i.e., integrated examples and problems) leads to better learning efficiency than lower (all problems) or higher (all examples) levels of assistance.

In these experiments, a "fixed" fading procedure was used to transition from examples to problems, inspired by the backward fading procedure reported by Renkl et al. (2002). While this procedure was effective, the transition point from examples to problems was selected somewhat arbitrarily. Moreover, the transition point was the same for all students. One might expect that an individualized fading procedure is even more effective. Such a fading procedure should be capable of recognizing the best transition point for any individual student. The basic idea is straightforward: a learner who has not yet gained a basic understanding of a problem-solving principle and of the way in which it is applied to solve problems should not be exposed to the corresponding problem-solving demands. Studying and self-explaining worked-out solution steps helps learners acquire an initial understanding of the problem-solving principle(s) to be used and thus prepares the learner to deal with subsequent problem-solving demands. Once the student shows a basic understanding of a principle and its application, s/he should go one step further and apply this knowledge to solve problem steps. But how to operationalize this idea as an adaptive fading procedure that can be implemented in a computer-based tutor?

Our first attempt at doing so was to extend the Cognitive Tutor so that it fades the examples dynamically based on an individual student's explanations of worked-out steps, determining the fading point separately for each of the problem-solving principles targeted in the instruction. Once a student shows that they are capable of explaining worked-out steps involving a particular problem-solving principle, the tutor transitions from worked-out to open steps for this principle. In implementing this procedure, we were able to take advantage of the fact that the Cognitive Tutor has students explain their steps (Alevan & Koedinger, 2002) and that it traces the development of students' knowledge through a Bayesian algorithm called "knowledge tracing" (Corbett & Anderson, 1995). We decided on a somewhat arbitrary fading point: the tutor

transitions from examples to problems, for a particular problem-solving principle, when its knowledge-tracing algorithm gives a .6 probability that the student is able to explain steps involving that principle.

In two studies, one a classroom study and the other one in the lab (Salden, Aleven, Renkl, & Schwonke, submitted; Schwonke et al., 2008), we found that example-enhanced Cognitive Tutor that adaptively faded the worked-out steps offers further learning benefits. The results of the lab study (Schwonke et al., 2008) show that adaptively fading worked-out examples leads to higher transfer performance on both regular post-test *and* delayed post-tests. While this effect was not fully replicated in the classroom study (Salden et al., submitted), a significant benefit in transfer performance for the adaptive fading condition over the problem solving condition was revealed on the delayed post-test. As such, the combined results of these studies show that an adaptively transitioning from examples to problems can be effective. Together, these studies provide a viable answer to the second key question related to the Assistance Dilemma, namely, when and how to fade the support that is initially provided to a learner.

While our fading procedures were found to be effective, they lack a strong theoretical basis for determining the optimal transition point. It seems likely that a more principled approach to fading worked-out examples would be even more effective. In line with a suggestion made by Koedinger et al. (submitted) we are working on developing a more principled Adaptive Fading procedure, grounded in the Assistance Dilemma. First, we will study the effect of a range of different (fixed) transition points. That is, we will collect data of the learning results of students as the transition point is varied. As described in Koedinger et al. (submitted) we expect to see a U-shaped relation between the transition point - i.e., as the number of examples that a student sees before transitioning to problems - and learning. Secondly, we will be to use the data collected in the first step to create a more principled adaptive fading procedure, in which the transition point for an individual learner will be determined by looking at “historical data” (i.e., the data collected in the first step) of learners like this individual learner. Besides producing more principled and potentially more effective fading procedures, this work will also lay the groundwork for further theoretical development towards a predictive model for the examples/problems dimension of the Assistance Dilemma.

REFERENCE LIST

- Atkinson, R. K., Renkl, A., & Merrill, M. M. (2003). Transitioning from studying examples to solving problems: Effects of self-explanation prompts and fading worked-out steps. *Journal of Educational Psychology, 95*, 774-783.
- Aleven, V., & Koedinger, K. R. (2002). An effective meta-cognitive strategy: learning by doing and explaining with a computer-based Cognitive Tutor. *Cognitive Science, 26*, 147-179.
- Aleven, V., McLaren, B., Roll, I., & Koedinger, K. (2006). Toward meta-cognitive tutoring: A model of help seeking with a Cognitive Tutor. *International Journal of Artificial Intelligence and Education, 16*, 101-128.
- Aleven, V., Stahl, E., Schworm, S., Fischer, F., & Wallace, R.M. (2003). Help seeking and help design in interactive learning environments. *Review of Educational Research, 73*, 277-320.

- Corbett, A. T. and Anderson, J. R. (1995). Knowledge tracing: Modeling the acquisition of procedural knowledge. *User modeling and user-adapted interaction*, 4, 253-278.
- Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist*, 38, 23-31.
- Koedinger, K. R., & Alevan, V. (2007). Exploring the assistance dilemma in experiments with cognitive tutors. *Educational Psychology Review* 19, 239-264.
- Koedinger, K. R., Pavlik, P., McLaren, B. M., & Alevan, V. (submitted). Is it better to give than to receive? The Assistance Dilemma as a fundamental unsolved problem in the cognitive science of learning and instruction. Submitted to the 30th Annual Meeting of the Cognitive Science Society, Washington D.C., July, 2008.
- McLaren, B. M., Lim, S., & Koedinger, K. R. (submitted). When is assistance helpful to learning? Results in combining worked examples and intelligent tutoring. Submitted to the 9th International Conference on Intelligent Tutoring Systems, Montreal, June, 2008.
- Renkl, A. & Atkinson, R. K. (2007). An example order for cognitive skill acquisition. In F. E. Ritter, J. Nerb, E. Lehtinen, & T. M. O'Shea (Eds.), *In order to learn: How the sequence of topics influences learning* (pp. 95-105). New York, NY: Oxford University Press.
- Renkl, A., Atkinson, R. K., Maier, U. H., & Staley, R. (2002). From example study to problem solving: Smooth transitions help learning. *Journal of Experimental Education*, 70, 293-315.
- Renkl, A., Atkinson, R. K., & Große, C. S. (2004) How fading worked solution steps works - a cognitive load perspective. *Instructional Science*, 32, 59-82.
- Salden, R. J. C. M., Alevan, V., Renkl, A., Schwonke, R. (submitted). Worked examples and tutored problem solving: redundant or synergistic forms of support? Submitted to the 30th Annual Meeting of the Cognitive Science Society, Washington D.C., July, 2008.
- Sweller, J., & Cooper, G. A. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition and Instruction*, 2, 59-89.
- Schwonke, R., Wittwer, J., Alevan, V., Salden, R., Krieg, C., & Renkl, A. (2007). Can tutored problem solving benefit from faded worked-out examples? In S. Vosniadou, D. Kayser, & A. Protopapas (Eds.), *Proceedings of EuroCogSci 07. The European Cognitive Science Conference 2007* (pp. 59-64). New York, NY: Erlbaum.
- Schwonke, R., Renkl, A., Krieg, C., Wittwer, J., Alevan, V., & Salden, R. J. C. M. (2008). *The worked-example effect: Not an artefact of lousy control conditions*. Manuscript submitted for publication.
- Trafton, J. G. & Reiser, B. J. (1993). The contributions of studying examples and solving problems to skill acquisition. *The Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society* (pp. 1017-1022). Hillsdale, NJ: Erlbaum.

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