

Are Worked Examples and Tutored Problem Solving Synergistic Forms of Support?

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Tutored problem solving with automated tutors has proven to be an effective instructional method. Worked-out examples have been shown to be an effective complement to *untutored* problem solving, but it is largely unknown whether they are an effective complement to *tutored* problem solving. Further, while computer-based learning environments offer the possibility of adaptively transitioning from examples to problems while tailoring to an individual learner, the effectiveness of such machine-adapted example fading is largely unstudied. To address these issues, two studies were conducted which compared a standard Cognitive Tutor with two example-enhanced Cognitive Tutors. The results indicate that adaptively fading worked-out examples leads to the highest transfer performance on delayed post-tests compared to the other two methods.

Background

One very successful approach in learning and cognitive skill acquisition is the use of “tutored problem solving” by intelligent tutoring systems (e.g., Koedinger & Alevan, 2007; VanLehn et al., 2005). Since Cognitive Tutors focus mainly on problem solving performance they can be further improved by providing worked-out solutions when the primary instructional goal is to gain understanding (e.g., Renkl & Atkinson, 2007). Additionally, since worked-out examples might not be as effective in later stages of the training (Kalyuga, Ayres, Chandler, & Sweller, 2003) a fading method should be employed in which the worked-out steps are gradually faded from worked-out examples to problems.

Two recent studies (Schwonke et al., 2007) investigated whether “tutored problem solving” and worked-out examples are redundant or synergistic forms of support. Their findings showed that tutored example fading in a fixed manner leads to more transfer than tutored problem solving alone and was also less time consuming. The authors suggested that the fading of examples could be even more beneficial for learning if the rate at which the worked-out steps are faded would be adapted to the students’ individual learning progress.

In order to investigate whether tutored problem solving and worked-out examples are synergistic when examples are adaptively faded, three experimental conditions were compared: 1) a problem solving condition which uses the standard Cognitive Tutor; 2) an example-enhanced Cognitive Tutor which fades worked-out steps in a fixed manner; and 3) an example-enhanced Cognitive Tutor which fades worked-out steps adaptively for each individual learner. The main hypothesis states that an adaptive fading procedure, combined with tutored problem solving, will lead to better learning and higher transfer than a pure tutored problem solving procedure and a fixed non-adaptive procedure for fading examples (also combined with tutored problem solving). The three experimental conditions were addressed in both a lab setting (in Freiburg) and a classroom setting (in Pittsburgh). By linking both lab and classroom settings a stronger and more authentic investigation of the experimental methods is created and possible effects will have higher implications.

Studies

For the Freiburg lab study students were recruited from a German high school and randomly distributed across the three experimental conditions and participated in two lab sessions. Furthermore, during the first lab session a pre-test and an immediate post-test were given and a delayed post-test during the 2nd lab session. The experiment focused on one section of a larger Unit in the tutor curriculum that deals with the geometric properties of angles. Furthermore, in contrast to the problem solving condition, the

students in the fixed fading condition received fully worked-out examples initially, which were gradually faded to pure problem solving. For the adaptive fading condition the build-up of worked-out steps was the same as the fixed fading condition up until the multi-step problems. Once students got to those problems any value step could be presented as either pure problem solving or as worked-out, depending on the student's performance explaining worked-out steps. The results showed that the adaptive fading condition attained a higher immediate post-test and delayed post-test performance than the problem solving and fading conditions.

The Pittsburgh classroom study took place at a vocational school which already uses the Cognitive Tutor for their Geometry curriculum. Overall, the materials and procedure were very similar to the German lab study with the difference that the study covered the entire angles Unit and had a longer duration. Additionally, pre- and post-tests were distributed and the delayed post-test was administered three weeks after the students finished working on the Cognitive Tutor. The results showed that when excluding the fixed fading condition, the adaptive fading condition did attain higher transfer performance on the delayed post-test than the problem solving condition.

Discussion

Two studies were conducted comparing "standard" tutored problem solving, with a Cognitive Tutor, versus two conditions in which tutored problem solving was enriched with worked-out examples. The worked-out examples were faded in either a fixed or in an adaptive manner. These manipulations were tested both in a lab study and in an actual classroom setting as part of a regular high school curriculum. Results of the lab study 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, a significant benefit in transfer performance for the adaptive fading condition over the problem solving condition was revealed on the delayed post-test. In short, the results indicate that the implementation of an adaptive fading procedure of worked-out examples within a Cognitive Tutor can be useful in both lab and actual classroom environments. Tutored problem solving and worked examples, adaptively faded, are *synergistic*, not redundant, forms of support.

References

- Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*, 23-32.
- Koedinger, K. R., & Alevan, V. (2007). Exploring the assistance dilemma in experiments with Cognitive Tutors. *Educational Psychology Review, 19*, 239-264.
- Renkl, A., & Atkinson, R. K. (2007). An example order for cognitive skill acquisition. In F. E. Ritter, J. Nerb, E. Lehtinen, T. O'Shea (Eds.), *In order to learn: How the sequence of topics influences learning* (pp. 95-105). New York, NY : Oxford University Press.
- 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.
- Van Lehn, K., Lynch, C., Schulze, K., Shapiro, J. A., Shelby, A., Taylor, D., Weinstein, A., & Wintersgill, M. (2005). The Andes physics tutoring project: Five years of evaluations. *International Journal of Artificial Intelligence in Education, 15*, 1-47.

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