Promoting Learning in Mathematics: Script Support for Collaborative Problem Solving with the Cognitive Tutor Algebra

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We combined two different instructional methods both of which have been shown to improve students' learning in mathematics: Learning with intelligent tutoring systems (Koedinger, Anderson, Hadley, & Mark, 1997) and collaborative problem solving (Berg, 1993). The problem-solving guidance provided by an intelligent tutoring system is effective, but because it places emphasis on learning problem solving skills, a deep understanding of underlying mathematical concepts is not necessarily achieved (Anderson, Corbett, Koedinger, & Pelletier, 1995). Collaborative activities can yield elaboration of learning content (Teasley, 1995) and thus increase the potential for the acquisition of deep knowledge, but students are not always able to effectively meet the challenges of a collaborative setting and tap this potential (Rummel & Spada, 2005). Collaboration scripts that prompt fruitful interaction have proven effectively in supporting collaborative learning (Kollar, Fischer & Hesse, in press). We believe that by combining intelligent tutoring and collaborative learning we could foster the advantages of both instructional methods and overcome their disadvantages. Collaborative interaction could augment the effects of an intelligent tutoring system by promoting deeper elaboration, and script support integrated in the tutoring environment could provide guidance to students as they collaborate and thus improve the quality of their collaboration.

Script Design

Our *collaboration script* was designed to guide students in collaborating while solving problems with the Cognitive Tutor Algebra (Koedinger et al., 1997), a tutor for mathematics instruction at the high school level. Its main features are immediate error feedback, the possibility to ask for a hint when encountering impasses, and knowledge tracing, i.e. the Tutor creates and updates a model of the student's knowledge and selects new problems tailored to the student's knowledge level. For the present study we focused on "systems of equations", content novel to the participating students. The script consisted of three components. First, it had a *fixed script component* that structured the problem solving process in two phases. During the *individual problem solving phase*, each student solved a problem in the Cognitive Tutor that consisted of one equation. In the *collaborative phase*, the two students joined on a single computer to solve a more complex system of equations problem that combined the two individual equations. They received instructions from the enhanced Tutor, e.g. prompting them to use collaborative skills. Second, the script had an *adaptive script component* that reacted when students met impasses that resulted in Tutor actions (e.g. hints). To encourage students to take advantage of these learning opportunities, the script asked the dyad to elaborate on the help received. Third, the script had a *metacognitive component*. Following each collaborative phase, students evaluated their collaboration and set goals for how to improve it during the next joint problem solving session. This component aimed at increasing students' ability to collaborate effectively even when no longer receiving script support. This is particularly important due to the risk of overscripting collaboration, i.e. motivation losses yielding reduced performance and learning, a phenomenon that has been discussed in conjunction with scripting for longer periods of time (Rummel & Spada, 2005).

Script Evaluation

We conducted a classroom study with a one-factorial design, comparing scripted collaboration with an unscripted collaboration condition in which students collaborated without support. This study was an initial, small scale study to establish basic effects and to test the procedure in a classroom setting. The study took place during three periods over the course of a week at a vocational high school outside of Pittsburgh in the U.S. Due to the disruptiveness of students in the same class using different interventions, we used a between-class design. The unscripted condition consisted of two classes (12 and 4 students), and the scripted condition consisted of one class (13 students). All classes were taught by the same teacher.

During day 1 and day 2 (*learning phase*), students learned how to solve system of equations problems. Depending on their condition, they collaboratively solved problems either with or without script support. On day 3 (*test phase*) we assessed students' individual and collaborative learning gains with three tests administered within the Cognitive Tutor and a paper and pencil test. The Tutor post-tests assessed the script's effect on students' *problem solving skills*. One post-test asked students to individually solve system of equations isomorphic to those during instruction, thus testing the individual's *retention* of the learned skills. A second post-test asked students to collaboratively solve system of equations without script support to assess the script's effect on improving *collaborative* problem solving skills. Learning from the script should also enable students to capitalize on future collaborations at the Tutor, i.e. it should *accelerate their future collaborative learning*. Hence, the third Cognitive Tutor post-test confronted students with a novel problem type: inequality problems. The paper and pencil post-test concentrated on assessing students' *conceptual knowledge* with two different

problem sets. Problem set 1 tested for students' understanding of the *basic concepts y*-intercept and slope: Multiple choice questions asked students to make transformations between verbal, algebraic and graphical representations of those concepts, and open format questions asked them to explain their answers. Problem set 2 assessed students' understanding of the main new *system of equations concept* learned: the intersection point. Again, students had to answer two types of questions: questions with discrete answer possibilities (correct or incorrect), and open format questions that asked for explanations. Scores were summed for each problem set. For answers to the multiple choice questions of problem set 1 (basic concepts), a maximum of 11 points could be reached; the possible maximum for explanations on basic concepts was 22 points. For problem set 2 (intersection point), the maxima were six points for discrete answer format and 12 for open format questions.

Results

The analysis was restricted to students who always worked collaboratively when present, as we are interested in the script's effect on collaborative learning in particular. Due to student absenteeism, only 9 students in the unscripted and 10 students in the scripted condition were included in our analysis.

First results of a MANOVA comparing performance of conditions in the paper and pencil post-test showed significant differences between conditions (Pillai-Spur, $F(4, 14) = 7.35$, $p < .05$). Means and standard deviations of the ANOVAs for each variable are displayed in Table 1. Answers to the multiple choice questions on basic concepts did not show a significant difference, $F(1,17) = 2.26$, *ns*. However, the scripted condition outperformed the unscripted condition on the discrete answer questions about the system's concept, $F(1,17) = 22.16$, $p < .01$. Significant differences between conditions was also found for the open format questions of both problem sets with $F(1,17) = 5.85$, $p < .05$ for the basic concepts and $F(1,17) = 17.01$, $p < .01$ for the system's concept.

Table 1: Means and standard deviations of the paper and pencil post-test, assessing conceptual understanding

	Unscripted condition		Scripted condition	
	M	SD	M	SD
Basic concepts: multiple choice	4.89	1.83	3.60	1.90
Basic concepts: open format	.22	.44	1.20	1.14
System concept: discrete answers	.89	1.45	4.50	1.84
System concept: open format	.44	1.33	5.70	3.59

Discussion and Outlook

The script had a significant effect on the acquisition of the main new concept of the system of equations unit, the intersection point. Particularly interesting are the substantial differences that were found for the open format questions of both problem sets, demonstrating a strong effect of the script on students' conceptual knowledge: After scripted interaction during the learning phase, students were better at articulating their mathematical thinking compared to their unscripted counterparts. It should be noted, however, that students in both conditions had difficulties providing explanations and only reached low scores in the open format questions. The amount of wrong explanations and the number of students who did not even try to articulate their thinking was very high. Thus, it might be promising to extend the learning phase in future studies to increase the script's effect. It remains to be seen if the script's effect can also be found in the Cognitive Tutor tests. Currently, we are analyzing the Tutor log files for variables such as number of errors per problem, time per problem, decrease of error rates over the course of several problems etc. Contrasting this post-test data with corresponding data from the learning phase will inform us on differences in students' learning progress. Results of the Tutor post-tests will be presented at the conference.

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