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Scripting Collaborative Problem Solving with the Cognitive Tutor Algebra: A Way to Promote Learning in Mathematics

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Interest in developing improved instructional methods for mathematics has increased since TIMSS and PISA. In our project, we introduce a new way to promote knowledge acquisition in mathematics: we enhanced the Cognitive Tutor Algebra, an intelligent tutoring system for learning mathematics in high school that only has been used for individual learning so far, to a collaborative learning setting. Although the Tutor has shown to increase learning, there also are several shortcomings. For instance, learning with the Tutor places emphasis on improving students' problem solving skills, yet a deep understanding of underlying mathematical concepts is not necessarily achieved. To reduce these shortcomings, we extended the learning environment to a dyadic setting, adding new learning opportunities such as the possibility to mutually elaborate on the learning content. A script was developed to guide students' interaction and to ensure that students profit from these new learning opportunities. The script structured students' collaboration in an individual and a collaborative phase and prompted students to engage in fruitful interaction. An adaptive script component provided hints when the dyad encountered difficulties in their problem solving. Finally, dyads engaged in a reflection activity following each problem to improve their collaboration over subsequent interactions. The scripts' effect on students' collaborative learning was tested in a classroom study that took place over the course of one week. We compared the learning of dyads collaborating at the Tutor without script support to the learning of dyads scaffolded by the script. To measure different aspects of learning, students solved several post-tests on the Tutor and with paper and pencil. The results of the paper and pencil test assessing improvement of students' conceptual understanding show significantly better performances of the script condition. The Tutor log data are still being analyzed and the results will be presented at the conference.

The Cognitive Tutor Algebra is 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. As several studies have shown, this Tutor improves learning by about one standard deviation compared to traditional classroom instruction (Koedinger, Anderson, Hadley, & Mark, 1997). However, students do not always benefit as much as they might from learning with the Tutor. First, a deep understanding of underlying mathematical concepts is not necessarily achieved since the Tutor emphasizes learning of procedural skills (Anderson, Corbett, Koedinger, & Pelletier, 1995). Second, students do not always make good use of the learning opportunities provided by the Cognitive Tutor. The collaborative extension we introduced to the Tutor environment aims at reducing these shortcomings. As research has shown, collaborative problem solving and learning have the potential to promote deep elaboration of the learning content (Teasley, 1995) and can yield improved conceptual understanding. However, students do often not show beneficial collaborative behaviours spontaneously (Rummel & Spada, 2005). Collaboration scripts have proven effective in helping people meet the challenges encountered when learning or working collaboratively (Kollar, Fischer, & Hesse, in press), thus we developed a script to prompt fruitful interaction on the Tutor.

For the present study we focused on "systems of equations", a content novel to participating students. Our *script* consisted of three components that aimed at facilitating students to capitalize on learning opportunities offered in the collaborative Tutor environment. The *fixed script component* structured the problem solving process in two phases. During the *individual problem solving phase*, each student solved a problem with one equation in the Cognitive Tutor. In the *collaborative phase*, 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 on collaborative skills like explanation giving. The division in individual and collaborative phases served to increase the individual's accountability for the joined problem solving and set up the preconditions for a productive interaction. Second, the script had an *adaptive script component* reacting 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 them to elaborate on the help received. Third, a *metacognitive component* followed each collaborative phase: Dyads engaged in a reflection of the group process to improve their interaction during the following collaboration.

To evaluate the script's effectiveness, we conducted a classroom study comparing scripted collaboration to an unscripted collaboration condition in which students collaborated without support. The study was an initial, small scale study to establish basic effects and to test the procedure in a classroom setting. Three classes taught by the same teacher participated. The unscripted condition consisted of two classes (12 and 4 students); the scripted condition consisted of one class (13 students). The study took place during three classroom periods over the course of a week. During day 1 and 2 (*learning phase*), students learned how to solve system of equations problems according to their condition. On day 3 (*test phase*), several post-tests were administered measuring different aspects of learning. Three post-tests at the Cognitive Tutor assessed students' *problem solving skills*. Two of the tests asked students to solve system of equations problems isomorphic to those during instruction, thus assessing the *retention* of the learned skills. One of these post-tests was solved individually, the second was solved collaboratively. The third test assessed *acceleration of future learning*: If the script succeeded in improving students' collaboration skills, learning to solve a novel problem type (inequality problems) in a collaborative setting at the Tutor should be easier for students who have had the advantage of script support during the learning phase. Finally, a paper and pencil test evaluated students' *conceptual knowledge* with problems that required applying the acquired concepts to new problem types. The test consisted of two problem sets, both composed of questions with discrete answer possibilities and open format questions asking for elaborated explanations. Problem set 1 tested for students' understanding of the *basic concepts y*-intercept and slope, problem set 2 assessed students' understanding of the main new *system of equations concept*: the intersection point.

The results of the paper and pencil test revealed substantial differences between conditions, i.e. the script condition yielded significantly better performances. The analysis was restricted to students who always worked collaboratively when present (9 students in the unscripted condition, 10 students in the scripted condition). The statistical data are displayed in Table 1. Particularly interesting were the results of the open format questions, demonstrating a strong effect of the script on students' conceptual knowledge: scripted interaction substantially improved students' ability to articulate their mathematical thinking. Scripted students also outperformed their unscripted counterparts in answering the discrete answer questions on the newly learned concept (intersection point). The discrete answer questions on basic concepts did not reveal significant differences. Results of the Cognitive Tutor post-tests will be presented at the conference.

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

	Unscripted condition	Scripted condition		
	Mean (SD)	**Mean (SD)**	**F (p)**	**η^2**
Basic concepts: discrete answers	4.89 (1.83)	3.60 (1.90)	2.26 (.151)	.18
Basic concepts: open format	.22 (.44)	1.20 (1.14)	5.85 (.027)	.26
System concept: discrete answers	.89 (1.45)	4.50 (1.84)	22.16 (.000)	.57
System concept: open format	.44 (1.33)	5.70 (3.59)	17.01 (.001)	.50