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Computer Simulation as an Instructional Technology in AutoTutor

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Abstract. We explored the impact on learning of interactive simulations that were coordinated with AutoTutor, a learning environment that helps students by holding a conversation in natural language. We randomly assigned 132 college students to one of three conditions: AutoTutor without simulations, AutoTutor with simulations, and a Monte Carlo AutoTutor that randomly generated dialogue moves. A pretest-posttest design was used to measure learning gains, as measured by objective multiple choice questions. All versions of AutoTutor were successful in promoting learning. The Monte Carlo AutoTutor produced significantly lower gains than the interactive simulation version for higher knowledge learners, and the direction of the three means were in the predicted direction. Improved simulation dialogues, modeling of good simulation manipulation strategies, and faster display of simulations are expected to enhance learning in future versions of AutoTutor.

1. Background

Constructivist views of learning emphasize the importance of the learner's active exploration and knowledge construction, rather than mere information transmission. One recent constructivist method to stimulate students' cognitive activity and facilitate their active construction of knowledge is a simulation-based environment. A number of early studies investigated the use of simulations as an instructional technology within computer-based learning environments [1]. Somewhat surprisingly, a mea-analysis of 93 studies conducted by Dekker and Donatti found mixed results on the effects of simulations [2]. The question arises as to why their evidence is inconclusive. Potential flaws in the studies might include poorly designed simulations, speed of display, difficulty of subject matter, and flexibility of user control.

Although there is a large body of research on computer simulations, researchers have not yet conducted research on the impact of simulations when it is coupled with dialogues. This motivated us to develop a tutoring system that constructs dialogues during the simulations, with guidance on how to use the simulations and suggestions on what to do next. The long-term goal is to create a computerized tutoring system that can select intelligent dialogue moves that can effectively guide the learner through a simulated environment [3].

2. AutoTutor

AutoTutor is a web-based computer tutor that holds conversations with students in natural language, that simulates dialogues that human tutors typically use, and that teaches students conceptual physics and computer literacy [4]. AutoTutor has an animated agent with a synthesized speech, facial expressions, and gestures. Recently AutoTutor has combined mixed-initiative dialogue with interactive simulations [3].

The simulation environment of AutoTutor is an embedded 3-D world with a set of parameters (e.g., speed of objects, distance between objects). The simulation environment was designed so that learners can use both slider and toggle controls to alter the simulations and run and rerun a simulation as many times as they desire. This allows users to practice at their leisure, and to learn at their own pace. Along with the simulations, there is corresponding tutorial dialogue which was designed to scaffold the learning process [4]. While simulations are running, AutoTutor stops at various points to portray relevant physics principles or to rectify misconceptions.

3. Present Empirical Study

The present study examined the efficacy of simulations and dialogues in AutoTutor. We compared three tutors: AutoTutor with conversation only, AutoTutor with interactive simulations, and AutoTutor with conversation generated by Monte Carlo generation of dialogue moves. AutoTutor with conversation only (AT) is the typical style of interaction from previous studies [4]. AutoTutor with simulations (AT-Sim) is the same as the conversation-only version except that it has the added component of simulations and the corresponding simulation dialogues. The third tutoring condition, the Monte Carlo tutor (AT-MC), does not use intelligent selection of the next dialogue move when trying to get the student to articulate a particular sentence-size expectation. Instead, a large number of dialogue observations were compiled from previous AutoTutor studies (associated with a particular expectation E) and the resulting distributions were used to determine the selection probability of different dialogue moves. AT-MC serves as a content control condition for the AT condition, but does not tailor particular dialogue moves to particular learners.

The current study assessed the effectiveness of the three different versions of AutoTutor and their respective impact(s) on learning. We predicted that learning gains would increase with the level of tutoring sophistication: AT-Sim > AT > AT-MC.

3.1 Methods

The participants were 132 students from Rhodes College and University of Memphis who were paid for their participation. The experiment consisted of three phases: a pre-test phase, a learning phase, and a post-test phase. During the pre-test phase, all participants were administered 26 multiple choice questions (pulled from the Force Concept Inventory). During the learning phase, participants answered four physics problems while interacting with one of the AutoTutors. The post-test phase consisted of a different set of 26 multiple choice questions (counterbalanced with the pre-test), and a user perception survey. The experiment took approximately two hours to complete.

3.2 Results and Discussion

We compared the three different tutors using four outcome indices: pre-test, post-test, simple learning gains (post test – pre test), and proportional learning gains [(post-test proportion – pre-test proportion) / (1 – pre-test proportion)]. The pre- and post-tests were converted to proportion correct scores.

There were no significant differences in pre-test scores between the tutoring conditions. Overall, we found that all the versions of AutoTutor produced significant learning gains; posttest scores (M =.60, SD =.18) were significantly better than pretest

Table 1
Means and Standard Deviations for Learning Measures.

Tutor conditions	Pretest	Posttest	Simple Learning Gains	Proportional Learning Gains
AT-Simulation	.459 (.18)	.633 (.17)	.174 (.14)	.309 (.25)
AT	.442 (.20)	.589 (.19)	.147 (.15)	.271 (.25)
AT-Monte Carlo	.464 (.20)	.582 (.18)	.118 (.13)	.237 (.27)

scores (M = .46, SD = .19), $F(1, 129)$= 141.17, $p < .001$, effect-size = 0.74. Although no other effects were significant, the data trend supported the predictions: AT-Sim > AT > AT-MC. Table 1 shows the cell means and SD's in the analyses.

A 2 (pre vs. posttest scores) x 3 (three tutor conditions) x 2 (low vs. high knowledge) ANOVA showed a significant interaction between test scores and a domain knowledge, $F(1, 90) = 23.44$, $p < .01$. The difference between pre and post scores was significantly greater for students with low domain knowledge than those with high domain knowledge. Thus, students with low knowledge benefited more from AutoTutor than those with a high knowledge. More interestingly, when we used participants whose pre-test scores were greater than .5, we found a significant difference in the simple learning gains between AT-Sim and AT-MC, $F(1, 28) = 4.19$, $p< .05$. AT-Sim produced significantly higher learning gains than AT-MC. This indicates that Monte Carlo tutor might inhibit learning for high knowledge participants and learning gains might suffer without adaptive dialogues.

We are currently in the process of revising the simulation dialogues and improving the simulation environments. Improved simulation dialogues, faster display of simulations, and modeling of effective learning with simulations might ultimately help students to learn deeply about abstract physics concepts. Interactive simulations will hopefully show some promise as a new medium for dialogue scaffolding, creating an immersive environment in which the learner and tutor can interact.

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