

Cognitive Tutor Effectiveness

Executive Summary of Research

Carnegie Learning's Cognitive Tutor is one of the most researched mathematics curriculum in use today. The Cognitive Tutor software has its basis in the ACT-R theory of knowledge and performance (Anderson et. al., 2004; Anderson, 2007). Following ACT-R, the Cognitive Tutor models complex problem solving as the coordination and strengthening of a large number of relatively simple "knowledge components." These knowledge components are collected into a "cognitive model" which allows the Cognitive Tutor to follow individual students' solution strategies and to track the growth of knowledge for each student over time.

The Cognitive Tutor employs mastery learning. Students need to demonstrate mastery on each knowledge component underlying a particular topic before they can proceed to the next topic. In this way, students set their own pace through the curriculum.

The tutor selects problems for each student in order to maximize the amount of time that students spend on knowledge components that they have not yet mastered and to minimize the amount of time that they spend on components that they have already mastered. Correct solution strategies are annotated with hints, which allow students to access instruction that is directly relevant to the problem they are working on and the strategy they are following within that problem. In addition to correct solution strategies, the cognitive model also includes information about common misconceptions and incorrect strategies and presents students with immediate feedback if they make common errors.

Several high-quality field trials have attested to the effectiveness of the Cognitive Tutor curriculum.

The Moore Oklahoma Independent School District conducted a randomized field trial comparing instruction based on the cognitive tutor curriculum to control classes using the McDougal-Littell Heath Algebra 1 textbook (Ritter, Kulikowich, Lei, McGuire and Morgan, 2007). In three schools, teachers taught some of their classes using Cognitive Tutor and some using the textbook. Results favored the classes using Cognitive Tutor as measured by first semester grades ($p=.002$, $d=.42$), final grades ($p=.007$, $d=.36$) and scores on the ETS Algebra I end-of-course exam ($p=.091$, $d=.38$). This study was recognized by the What Works Clearinghouse as fully meeting their evidence standards.

Koedinger, Anderson, Hadley and Mark (1997)¹, in a matched control group quasi-experimental study of Pittsburgh Public School students taking Algebra 1, found that Cognitive Tutor students

¹ The results reported here are from an unpublished reanalysis of this data in Koedinger, Ritter and Wolfson (2007). This reanalysis used Hierarchical Linear Modeling to control for clustering and equated students at pretest for each outcome measure, using scores from the California Achievement Test (CAT5). Control group students showed small advantages on the CAT5, and the advantage at pretest was significant for the subgroup of students who took the Multiple Representations post-test.

outscored the control group on four separate measures: the SAT ($p=.01$, $d=.29$), the Iowa Algebra Aptitude Test ($p=.02$, $d=.16$), the problem situations test ($p<.001$, $d=1.0$) and a multiple representations test ($p<.001$, $d=.68$).

Shneyderman (2001) conducted a quasi-experimental study looking at performance of students at six high schools in the Miami-Dade County Public School District. The students constituted a subset of students at those schools that had taken Algebra 1 and were equated at pretest both academically (using FCAT-NRT) and on various demographic characteristics (ethnicity, gender, free or reduced lunch status and limited English Proficiency). Following their Algebra 1 class, Cognitive Tutor students outscored the control group on the ETS Algebra 1 exam ($p<.01$, $d=.22$). No significant difference was observed on the end-of-year FCAT-NRT. Students in the Cognitive Tutor group passed the course at a higher rate than students in the comparison group.

Sarkis (2004) conducted a quasi-experimental study that looked at FCAT performance for 6,395 students at ten Miami-Dade County high schools, based on whether students used the Cognitive Tutor curriculum. The study found no significant difference on final grades but it found that Cognitive Tutor students significantly outscored control group students on the FCAT ($p<.001$, $d=.11$). Results for students identified as having Limited English Proficiency also favored Cognitive Tutor ($p<.001$, $d=.28$) as did results for students in Special Education programs ($p<.001$, $d=.78$).

Plano, Ramey and Achilles (2005) reported the results of a regression discontinuity study looking at ninth grade Algebra students in the Kent, Washington School District. Students receiving below a C in their prior-year mathematics course were assigned to use Cognitive Tutor; those receiving above a C took a traditional course. The Achievement Levels Test developed by the Northwest Evaluation Association was used as both pre- and post-test to measure the improvements in learning for the two groups. The results showed that Cognitive Tutor students learned significantly more, according to this measure ($p<.05$, $d=.33$). Results were reported to be even stronger for the subgroup of students identified as English Language Learners and for students receiving free or reduced lunch, but standard deviations were not included for these subgroups and so effect sizes cannot be calculated.

A randomized field trial of a number of educational technologies conducted by the US Department of Education (Campuzano, Dynarski, Agodini, & Rall, 2008) did not find any significant difference between students in the Cognitive Tutor condition and those in a control group. However, for the combined algebra products, there was a statistically significant increase in results from the first to the second year, leading to an advantage for the algebra technologies over the control group in the second year ($p<.05$, $d=.15$)². We believe that this finding emphasizes the need to provide teachers with training and time to adjust to the type of instruction provided by the Cognitive Tutor, and our implementation plan in this project takes this need into account.

² The study was not designed to provide enough power to detect specific product effects from the first year to the second, so this result is pooled across the products in the study, rather than specific to Cognitive Tutor.

One randomized controlled trial of the Cognitive Tutor Geometry curriculum (Pane, et. al., in press) showed negative results ($p=.03$, $d=-.19$). Although we are concerned with this finding, we believe that they do not argue against our expectations for positive results in this study. The study researchers attribute the negative results to implementation problems in the urban district in which the study took place (Ikemoto et. al., submitted). Another consideration was the lack of focus in the Cognitive Tutor on geometric construction and proof. As a result of this finding, our software has been updated to include more focus on these topics.

On the basis of these results, the RAND corporation was awarded an IES Goal 4 evaluation grant, which is currently evaluating the effectiveness of Cognitive Tutor Algebra 1 in a randomized control trial spanning seven regions and over 120 schools.

In addition to these field trials evaluating a full-year Cognitive Tutor implementation, researchers have conducted dozens of small-scale evaluations of individual units of instruction within the tutor. For example, Alevan and Koedinger (2002) compared two versions of the Cognitive Tutor instruction focused on reasoning about angle measures in a diagram. They found that students who were asked to articulate the reasons or geometric theorems relating angles in a diagram outscored those who were asked simply to provide the angle measures. Subsequent to these experiments, the Cognitive Tutor software was revised to include student use of geometric reasons as a fundamental part of the task. Butcher and Alevan (2008) conducted several experiments that showed that closely integrating visual reasoning about geometric diagrams with the numeric and symbolic reasoning required to determine angle measures leads to more robust learning. The most recent version of the Cognitive Tutor software incorporates these changes as well. Cen, Koedinger and Junker (2007), in a field experiment, used data from prior-year implementations to fit various parameters controlling the learning rate within the Cognitive Tutor and found that, with properly fit parameters, students could reach the same level of performance in 12% less time.

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