

Carnegie Learning's Adaptive Learning Products

Steven Ritter

Ryan Carlson

Michael Sandbothe

Stephen E. Fancsali

Carnegie Learning, Inc.

437 Grant Street, 20th Floor

Pittsburgh, PA 15219 USA

1.888.851.7094 {x122, x219}

{sritter, rcarlson, msandbothe,

sfancsali}@

carnegielearning.com

ABSTRACT

Carnegie Learning, developers of the widely deployed Cognitive Tutor, has been working on several new adaptive learning products. In addition to demoing the Cognitive Tutor, an educationally effective intelligent tutoring system for mathematics that has been the subject of a great deal of educational and educational data mining research, we demo two iPad apps, an equation solving app that recognizes hand writing and a game for developing math fluency using fraction comparison tasks. A wide variety of datasets over the years have been analyzed from the Cognitive Tutor, and in recent years several new features have been introduced that may be important to researchers. This demonstration will introduce those unfamiliar with Cognitive Tutor to the system and serve as a refresher for those unaware of recent developments. It will also introduce our new iPad apps to researchers.

Keywords

Cognitive Tutor, intelligent tutoring systems, real-world implementation, mathematics education, educational games, iPad, mathematics fluency, fractions, decimals, multiple representations, equation solving, cognitive modeling

1. COGNITIVE TUTOR

Carnegie Learning's Cognitive Tutor (CT) [7] is one of the most widely used intelligent tutoring systems (ITSs) in the world, with hundreds of thousands of users in middle schools, high schools, and universities throughout the United States and abroad. CT has been demonstrated effective in one of the largest randomized trials of its kind involving educational software, providing substantive and significant improvement in learning gains, compared to a control group using traditional textbooks, in the second year of implementation for a large cohort of high school students from diverse regions of the United States [6].

A variety of datasets providing information about learner interactions with the CT have been made available by Carnegie

Learning via the Pittsburgh Science of Learning Center LearnLab's DataShop repository [5]; the learning sciences community and others have used these and other datasets in a correspondingly wide variety of educational and educational data mining (EDM) research projects, including many throughout the history of the *International Conference on EDM*. Some datasets used are from relatively older versions of the CT software. Even relatively old data can enable discovery and insight into issues like improving cognitive models and improving the predictive accuracy of models of student behavior, but as can be expected, CT, like any other piece of widely deployed software, evolves over time. Elements of this evolution may impact the types of substantive conclusions that can be drawn from CT data or contribute to creative new modeling approaches and target educational phenomena. In this demonstration, we will provide an overview of the basic interface of the CT and its approach to mathematics education as well as highlighting several newer features that have been deployed in the last few years. We will also, as appropriate, highlight several nuances and issues that arise when CT and Carnegie Learning's middle school math product based on CT, called MATHia, are deployed in real-world classrooms. Some of these nuances and issues may have important implications for how EDM analyses are conducted using CT data.

Our demo will provide a general overview with CT and focus on the following features of CT and MATHia: lesson content and manipulatives, step-by-step examples, review mode, promotion & placement changes, interest area & name customization (MATHia), and math "Fluency Challenge" Games (MATHia).

2. AN IPAD RACING GAME TO ENHANCE MATH FLUENCY

Developers at Carnegie Learning are also developing an iPad car racing game (Figure 1) to enhance math fluency for tasks like comparing fractions. The game integrates with the Hyper-Personalized Intelligent Tutoring (HPIT) system [4], a distributed web service plugin architecture that enables "on-the-fly" personalization based on (non-)cognitive factors. Gameplay is predicated on learners rotating the iPad to direct a car to the right, left, and in between "flags" that display values of fractions (or decimals, etc.) based on whether a value displayed on the car is greater than or less than values displayed on flags, creating a sort of number line on the game's "road."

Time pressure, introduced via a countdown clock, serves gameplay and cognitive functions. Time pressure on tasks like fraction comparison will encourage learners to develop dynamic

strategies to carry out such tasks (e.g., imagining slices of a pie vs. finding common denominators). Learners' successful adoption of diverse strategies is a marker of math fluency that will decrease working memory load on such tasks. We posit that fluent math learners are more likely to succeed in more advanced math.

Game content and behavior are configurable to allow education researchers, without programming, to rapidly prototype and build a range of experiments. Researchers can, for example, specify number sequences encountered as well as "level" structure that groups similar content together. We support in-game feedback (e.g., text displayed after questions, pausing after incorrect actions for review) via an XML run-time scripting engine.



Figure 1. Sample problem: The player's value is $1/9$, and since $1/9 < 1/7$ the player moves to the left lane before passing the flags.

A conceivable experiment uses multiple graphical representations to develop fluency [1]. Curricula can begin with a level containing common numerator fractions, then common denominator fractions, and then mixed fractions. Scripting provides for dynamic annotations of each fraction with pie slice or number line images above flags to help players visualize the comparison (e.g., loading web images and reacting to each level's content). Help can be offered only when a student is struggling (e.g., making at least one error), and HPIT can drive A/B tests, distributing content/scripts to control and experimental groups.

3. AN IPAD APP FOR EQUATION SOLVING

Researchers at Carnegie Learning are also working on an iPad app to support math equation solving practice. The app combines technology from CT with an interface that recognizes human handwriting (Figure 2). Following the lead of CT and building on earlier work on handwriting-based tutors [2], the app provides context sensitive feedback and hints while also providing the capability to "trace" student knowledge using, like CT, the Bayesian Knowledge Tracing (BKT) [3]. Integrating the app with HPIT provides the ability to adapt to cognitive factors (e.g., BKT) and non-cognitive factors (e.g., grit, self-efficacy, etc.).

The app will advance student learning about equation solving and our understanding of that learning in at least two ways. First, handwriting recognition will provide for an experience that is more akin to a traditional "pencil and paper" approach to equation solving practice than the approach provided by CT in which actions like "combining like terms" to manipulate sides of an equation are chosen from a drop-down menu. Second, logging such equation solving will provide rich data to better understand the learning of equation solving in this more natural setting.

Moving away from the menu-based CT approach introduces challenges. Handwritten equation solving allows for a variety of math errors that simply are not allowed by CT. Further, new

knowledge components (or skills) must be introduced to the cognitive/skill model for this app; skills, for example, related to the understanding of equality (e.g., that the equation symbol must persist from line to line as the student works toward an equation solution) should be tracked. Such skills are not tracked in CT's menu-based equation solving because the equation symbol persists from step-to-step in CT. Comparing skill models and learner performance across platforms is a key area for future research; translation of skill models across platforms is an important issue as technology permeates teaching and instruction.

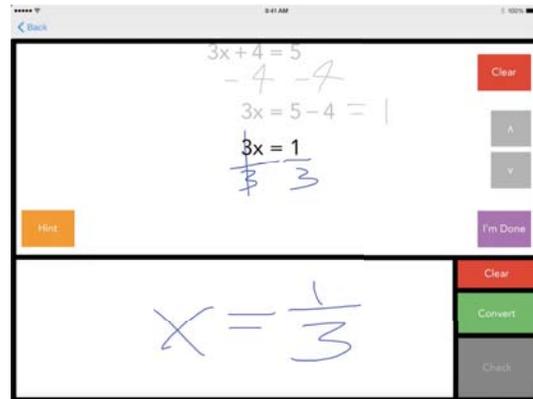


Figure 2. A user solves the equation $3x+4 = 5$, writing the final step of the equation as $x = 1/3$.

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