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Gender and Cognitive Differences in Help Effectiveness During Problem Solving

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We identified gender and cognitive differences in two problem solving tutors developed for K-12 students. Learning results improved once hints were adapted to a student's basic cognitive skills. For example, students with low cognitive development learned more when they interacted with concrete objects on the screen. Girls spent more time with hints, their perception of the system was more positive and they were more motivated than boys to use the system again. Animation improved learning results by as much as 25% as compared to the system without animation. These gender and cognitive differences are described in this article.

Keywords: Intelligent tutors, mathematics education, gender differences, cognitive development, multimedia.

This article describes two problem solving tutors, one for elementary mathematics and another for SAT-Math. The research focused on modeling individual student cognitive characteristics and resulted in the general conclusion that enhancing user models with detailed information about user cognitive characteristics leads to improved response to instruction. This is especially important to consider for domains in which there are well-established group differences, such as gender differences in mathematics. This research extends the importance of the model tracing approach and argues that enhanced user modeling can further optimize the advantages of individualized instruction.

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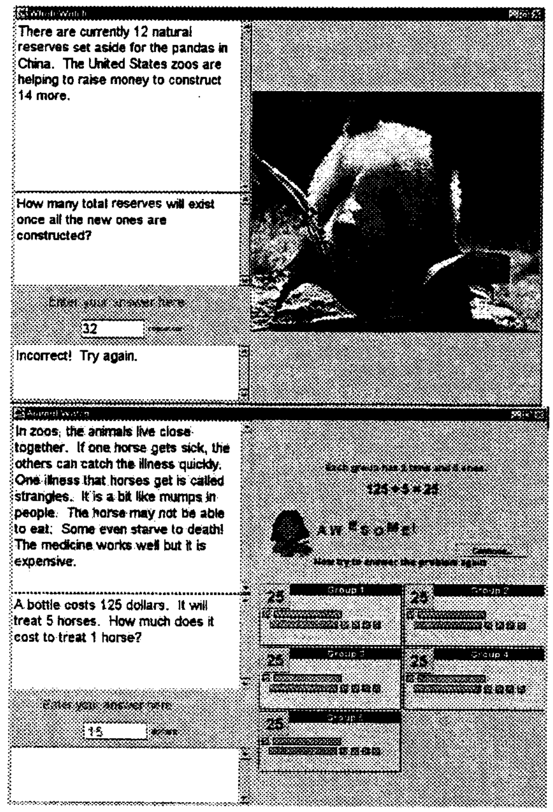

FIGURE 1
Animal Watch, Arithmetic Tutor, The tutor presented a variety of problems including addition (top) and division (bottom) problems. When a student made a mistake, the tutor presented either a simple text response (top) or manipulative hints (bottom), in which case the student used five group of rods of 25 units each to solve the division problem (125/5).

This article describes work to integrate information about individual student cognitive characteristics into two mathematics tutoring systems. Enhanced user models were used to adapt instruction by selecting from a range of qualitatively different kinds of help. This research approach encompassed the search for effective teaching strategies to 1) articulate the link between cognitive skills and individual learning, and 2) individualize teaching through cognitive and student models. Research was carried out on two different systems, an intelligent tutor for elementary mathematics and another for SAT-Math as described below.

AnimalWatch, an intelligent tutoring system for arithmetic, includes approximately 1000 mathematics word problem templates and associated instruction for topics from simple addition through fractions and mixed numbers.[1] The word problems focus on material about endangered species; as students work on the problems, they learn about the species, their history, habitat, environmental threats, and so on, Figure 1. Problems in AnimalWatch are adaptively selected depending on the student's cognitive mastery of different skills, and taking into account problem difficulty factors. Because AnimalWatch was designed to encourage positive attitudes towards mathematics among students at the end of elementary school the software follows an immediate help provision model; when students make an error, the tutor responds with help, including a text message, a simple hint, or a more extended explanation. The immediate provision of help was designed to support students' beliefs that they could succeed in solving difficult problems through effort and support, and to forestall the self-derogatory attributions reported by some female students that they lack the ability to solve difficult problems. We investigated the impact of different forms of instruction in relation to student cognitive developmental level (e.g., concrete vs. formal operational thought), as diagnosed with cognitive tests. Hints are provided immediately when students enter an incorrect answer. Initially, student errors elicit a simple text message (e.g., "Try again," "Are you sure you are adding 35 and 75?").

Results of tests of hundreds of students using this tutor showed an interaction of gender, cognitive developmental stage, and type of help received, in predicting learning rate. Bonferroni confidence intervals revealed that students of high cognitive development ("abstract" reasoners) learned more with numerical approaches, while students of low cognitive development ("concrete" operational) learned most when explanations were aided with concrete Cuisenaire rods and other sort of counters. The results indicated that students' response to different forms of instruction provided by AnimalWatch varied also with gender. In particular, the effects were stronger for boys than for boys; girls spent much more time within each hint (25-30% more time on average). One hypothesis is that girls compensated with further effort working on the problem thus reducing the effect of the different kinds of help. Meanwhile, boys may have given up on the help earlier when they were frustrated. Our general conclusion from these studies was that adding information about young students' cognitive development would allow the user model to dynamically select the type of help that would be most useful for individuals (Arroyo et al, 2000; Arroyo et al., 2001; Arroyo, 2003).

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[1] *AnimalWatch* tutor may be downloaded at http://sophia.cs.umass.edu/AWE.

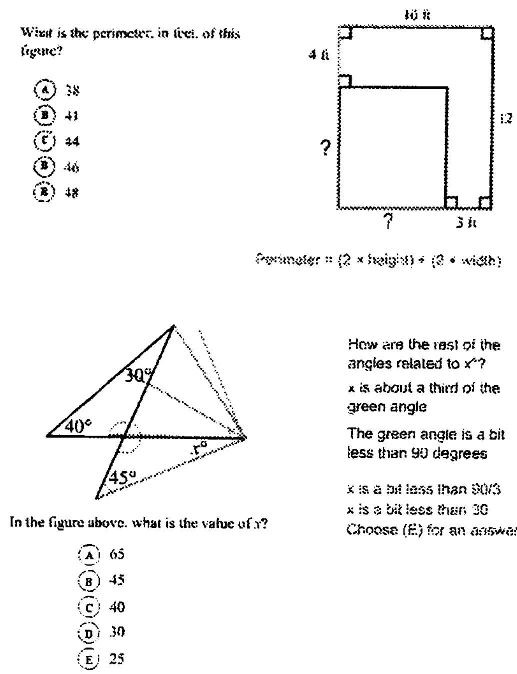

FIGURE 2
Wayang Outpost, Geometry Tutor. Two forms of help are available in Wayang. A fairly traditional analytic approach, such as setting up equations (below or to the right of the figure) is available. Visual hints (lines added to the figure) suggest the student mentally invert the cut-out portion to reveal the intact rectangle, suggesting that the missing lengths are already known (top) or animated lines on the triangle (bottom) propose that the student mentally translate angles to determine the missing value.

The second tutor, Wayang Outpost for geometry, provides instruction via a web site, ensuring easy access to students either at home or from any school connected to the Internet.[2] The setting is an animated classroom based in a fictitious research station in Borneo, which provides a rich real-world context for mathematical problems involving endangered species. If the student answers the problems incorrectly, or requests help, multimedia explanations provide step-by-step instruction and guidance in the form of Flash animations with audio, Figure 2. For example, on a geometry problem, the student might see an angle with a known value rotate and move over to the corresponding angle with an unknown value on a parallel line, thus emphasizing the principle of

[2] *Wayang Outpost* may be accessed from http://wayang.cs.umass.edu/.

correspondence. Explanations and hints therefore resemble what a human teacher might provide when explaining a solution to a student, e.g., by drawing, pointing, highlighting critical parts of geometry figures, and talking, rather than a heavy reliance on screen-based text.

Like AnimalWatch, Wayang Outpost was designed with several forms of help, to respond effectively to differences in students' cognitive skills. Numeric hints showed how to construct algebra equations to solve the geometry problem. Spatial hints showed transformations, including how to move angles and lines that would make the problem easier to solve and improve visual estimations. These visual strategies are often rapid and involve fewer computations than numeric strategies. Although they may be somewhat imprecise, in the context of multiple choice assessments such as the SAT-Math exam, visual-estimation strategies can lead students to a plausible correct answer in a relatively short period of time, and can reduce the possibility that simple computation errors will result in the wrong answer choice.

This major hypothesis was evaluated with nearly 300 students who worked with a version of Wayang Outpost that was either tuned to draw heavily on text and equations or animation. A study was carried out in an urban area school in Massachusetts, where 100 students were given three tests before using the tutor: pretests involving SAT-Math problems and online tests of the student's mathematics fact retrieval ability and 3-D mental rotation abilities.

The tutor itself showed learning improvement. A repeated-measures ANOVA revealed a significant overall difference in percentage of questions answered correctly from pre- to post-test, $F(1,101)=20.20$, $p=.000$. Students showed a 27 percent increase over their pre-test score at post-test time ($M=22.60$, $SD=13.40$) to post-test ($M=28.62$, $SD=12.53$), an 8% overall improvement in just a couple of hours. There were no significant interactions with either gender ($p=.46$) or type of help ($p=.58$). Additional analyses of specific classrooms revealed increases ranging from seven to 300 percent over the pretest score. A second repeated-measures ANOVA revealed a significant change in the percentage of questions skipped with no answer, $F(1,84)=15.62$,$p=.000$. Students left significantly fewer questions blank in the post-test ($M=5.09$, $SD=13.45$) than in the pre-test ($M=15.10$, $SD=24.70$). Thus, the Wayang tutor was effective in its goal of improving student performance on SAT-Math geometry problems. Students who used Wayang significantly increased percent correct and decreased percent skipped questions from pretest to posttest, quite encouraging for the short period of time (2 hours) students were exposed to it.

Despite the fact that females did not improve more than males, their perception of the system was more positive than for males, and their willingness to use it again was more positive. Males and females did not differ on the online measure of mental rotation, and females outperformed males on math-fact retrieval speed and accuracy, while in the past males have generally been found to outperform their female peers on measures of math-fact retrieval speed (Royer, Tronsky, Chan, et al., 1999). Students who were fast and accurate on the math-fact retrieval task performed better on the post-test than those students who were slow and inaccurate, affecting their actual learning. This suggests that training cognitive skills such as accuracy and speed of retrieval of mathematics facts (such as multiplication tables, addition, etc.) affects not only overall performance in a test, but also actual learning with the tutoring system.

Overall, as evidenced by various help seeking data, students in the visual condition were more engaged by the help than those in the analytic condition. Specifically, students in the visual condition saw more hints and interacted more with the help function than students in the analytic condition, regardless of their incoming ability. Perhaps students were more attracted to the visual help since its strategies are not often presented in the classroom. The tutor was extremely beneficial for students in general, with high improvements from pre to posttest. Girls were especially motivated to use the fantasy component (which involved female "role models") and especially thought highly of the system. Some results showed how adapting the provided hints to students' basic cognitive skills (matching teaching strategies to students' cognitive strengths) can yield higher learning results (Arroyo et al., 2004).

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