International Conference on Mathematics/Science Education & Technology (M/SET 2000), San Diego, CA, March 2000.

Gaining Confidence in Mathematics: Instructional Technology for Girls

Carole R. Beal
Department of Psychology
Cbeal @psych.umass.edu

Beverly P. Woolf, Joseph Beck, Ivon Arroyo, Klaus Schultz, David M. Hart
Center for Computer-Based Instructional Technology
Computer Science Department
{bev, beck, ivon, schultz, dhart}@cs.umass.edu

University of Massachusetts
Amherst, MA 01003

Abstract: AnimalWatch is a mathematics tutor with enhanced adaptive feedback precisely tailored to girls' instructional needs. Three evaluation studies with fifth grade students support our hypothesis that adaptive feedback is beneficial to girls' math confidence. We have also had high levels of teacher participation including classroom activities, after-school presentations and summer workshops. This paper describes features of the tutor, evaluation studies, work with classroom teachers and dissemination activities.

1. Increasing Girls' Self-Confidence in Mathematics

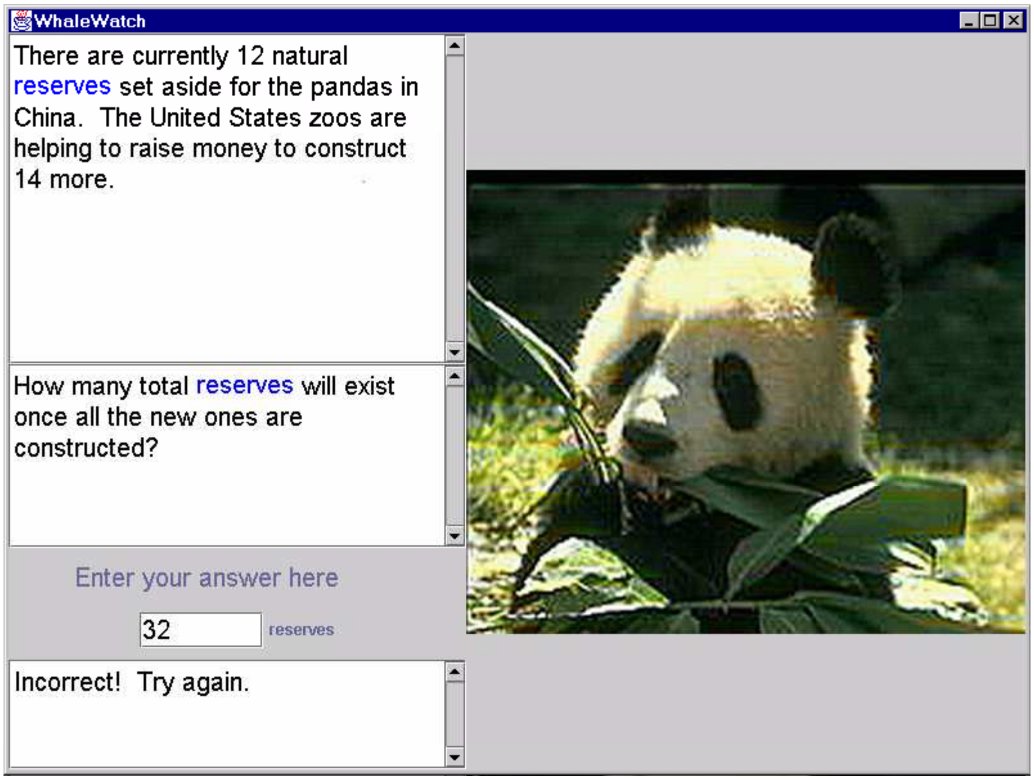
A major factor contributing to women's lower participation in science, engineering and mathematics careers is that, beginning in junior high school, many girls begin to doubt their ability to learn mathematics (Beal, 1994; Beller & Gafni, 1996). As a result, girls are typically more likely than boys to progress no further in mathematics than eighth grade algebra, and are subsequently under-prepared for many science and math-intensive majors and programs at the university and graduate school levels.

This project focuses on development of an intelligent tutor to provide effective, confidence-enhancing mathematics instruction for girls in late elementary school (Hart et al., 1999). The guiding hypothesis is that mathematics instruction in the United States can be completely transformed through the use of instructional technology so as to be much more appealing to girls, and in turn, enhance girls' interest in and preparation for math and science careers.

In contrast to most educational software which is designed primarily with the male user in mind, AnimalWatch provides supportive, adaptive and effective math instruction tailored to girls' interests and needs. AnimalWatch accomplishes this via its "student model," a module that draws on cutting edge techniques in artificial intelligence to create a representation of each student's math understanding. The student model is continually updated as the student works on math problems and is used to 1) generate appropriately difficult problems and 2) to respond to the student's errors with customized help and feedback tailored to her or his needs. AnimalWatch also engages girls' interest in math by blending mathematics with environmental biology, the science subject that is of highest interest to female students.

AnimalWatch has been developed with the collaboration of local schools to help students learn fractions, decimals and percentages at a 5th-6th grade level. In contrast to common drill-and-practice systems, intelligent tutoring systems modify themselves to conform to the students' learning styles. Once the student demonstrates mastery of whole numbers, the tutor presents simple fractional problems that require increasingly challenging application of the cognitive subtasks involved in solving the problems (e.g. adding fractions with like denominators, adding fractions with different denominators, etc.).

When a student has trouble solving a problem, AnimalWatch initiates a tutoring interaction with customized hints and guidance that helps the student work through the problem. Similar problems involving the same subskills are given until the student can successfully work the problems. AnimalWatch maintains an accurate assessment of

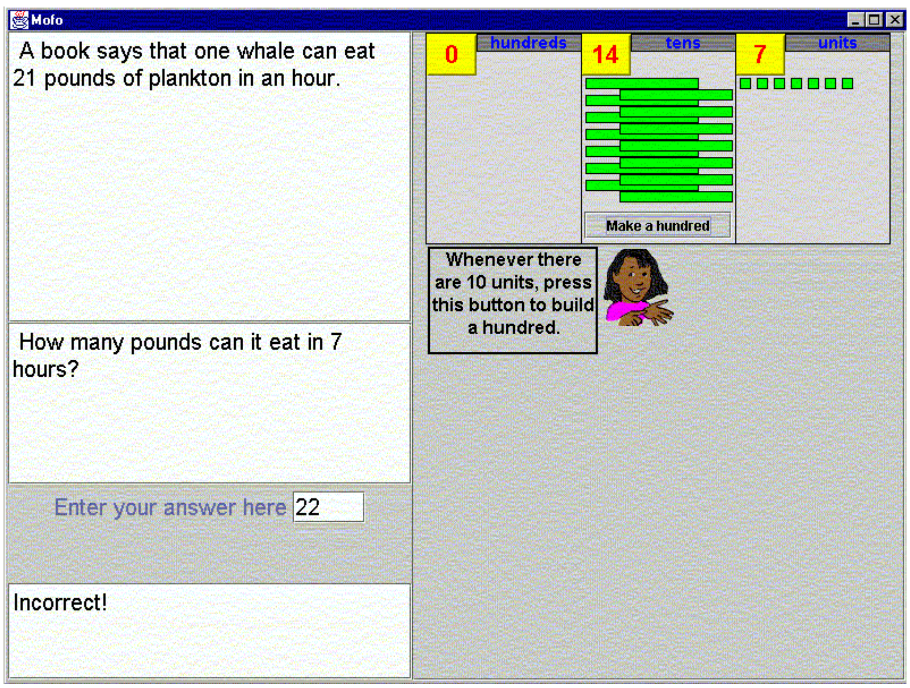


the student's strengths and weaknesses. Online self-assessment surveys conducted as students work with AnimalWatch have showed that the tutor generates a more accurate assessment of each student's abilities than the students themselves (Beck et al., 1997).

Figure 1: Example of addition problem in AnimalWatch

AnimalWatch uses Artificial Intelligence techniques for problem generation, hint selection and student modeling (Stern et al., 1999). Multimedia is used judiciously to engage the student by animating key concepts and providing interactive manipulables based on those used by classroom teachers.

Figure 2: Example of a hint on a simple multiplication problem



2. Features for Girls in AnimalWatch

When the student logs on, he or she enters an environmental biology storyline in which math problems are presented within distinct contexts that unfold as the narrative progresses. Students can select an endangered species, such as the Right Whale or the Giant Panda, which includes an initial story context. The student is invited to join an environmental monitoring team and engagesin activities to prepare for the trip.

For example, in the case of the Giant Panda, problems involve research at the library about the Panda's habitat, reading about the birth of a new Panda at the San Diego Zoo, estimates of the expenses associated with a trip to China, and analyses of the rate of decline of the Panda population over time, etc. The student model estimates when the student is ready to move on to the next environment (e.g., whale-watching vessel; mountain terrain trip, etc.). Each math problem includes graphics tailored to the problem, e.g., a map of Cape Cod bay showing the migration route of the Right Whale for a problem in which students calculate the fractional progress of a pod over the course of a week's travel. The third context involves a return to the research "base" and preparation of a report about the species' status.

Hints and instruction screens appear when the student has made a problem solving error (example shown in Figure 2). Hints and adaptive feedback have been shown to be especially important to girls, whereas boys retained their confidence in math even when working with a drill and practice version of the system that simply presented problems and responded to student errors with the message, "Try again." This gender difference in response to different types of feedback is consistent with the theoretical framework: Detailed and immediate help provides a critical role for lower-confidence students, many of whom are female, who are quick to assume that they do not have the ability to understand difficult concepts.

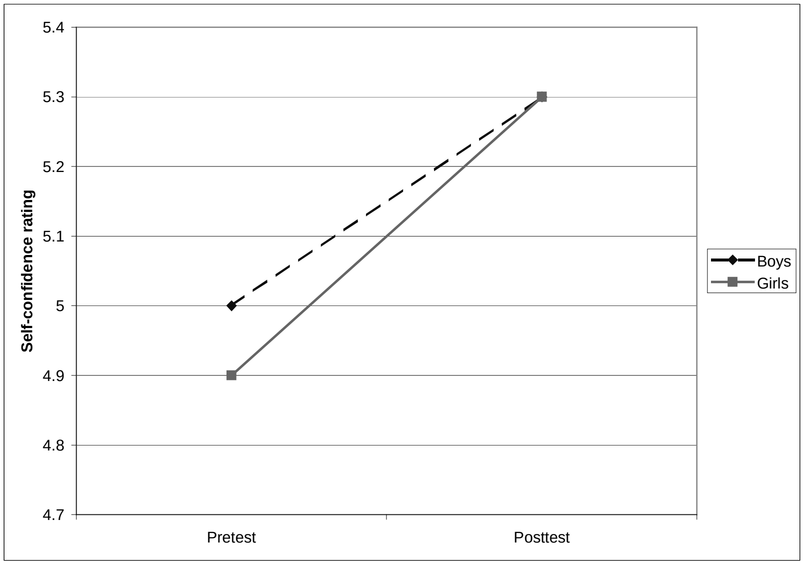
The intelligent student model is continually updated based on the student's ongoing performance. Math problems in AnimalWatch are not "canned" or pre-stored. Rather, hundreds of problem templates are used to generate novel problems "on the fly." AnimalWatch currently includes mathematics operations that match those included in most fifth grade classrooms: whole number operations (multi-digit addition/subtraction, multiplicaton/division); introduction to fractions; addition and subtraction of like and unlike multi-digit fractions; reduction/simplification; mixed numbers; introduction to proportions/ratios; and interpretation of graphs, charts and maps. AnimalWatch has been implemented in the Java computer programming language inorder to be easily disseminated via CD-ROM or the Internet and easily used by most elementary schools.

3. Project Findings: Evaluation Studies with AnimalWatch

Results from three evaluation studies will be described. The first study focused on collaborative learning, and, consistent with students who worked individually, students who worked with a partner showed significant increases in math self concept (Berry, et al., submitted). The increase in math self confidence was observed for girls working with a male partner, as well as those working with another girl. In terms of math confidence and objective problem solving, these results indicate that girls do well with AnimalWatch even when working with a male partner.

The effectiveness on girls' and boys' performance of different types of adaptive feedback was measured in June 1999 with three classes of fifth graders. Preliminary evidence showed that highly adaptive feedback is especially important to girls: when students worked with a version of AnimalWatch with the adaptive feedback "turned off," girls were more negatively affected than boys. The goal was to identify specific hints and help that are most beneficial to girls, particularly those who are at different stages of cognitive development.

In this study, students worked with AnimalWatch for three sessions over the course of one week. AnimalWatch was adjusted to compare responses to different types of hints, such as those shown in Figure 4. When the student made a mistake, the system first provided messages with relatively little content, e.g., "Are you sure you are using the correct operation?" Low interactive text hints were used at first because nearly half of the errors entered are corrected by students on the next try after a simple prompt. If the student kept entering a wrong answer, the system presented a hint to guide the student in the whole problem-solving process. At this point, AnimalWatch selected randomly either hints that were highly conceptual (see Figure 2) or hints that were more procedural in nature (see Figure 4). Hints also varied in the degree of interactivity required from the student: hints that were highly interactive



were also highly structured and walked the student through the solution process in incremental steps (see examples in Figure 4). We hypothesized these would be more helpful to girls.

Figure 3: Change in Confidence of Girls and Boys

Data on math problem solving were automatically collected. Hint effectiveness was assessed by comparing the number of errors made on subsequent problems of the same type, the idea being that if a particular hint is helpful then the student should be able to to solve a similar problem with significantly fewer errors.

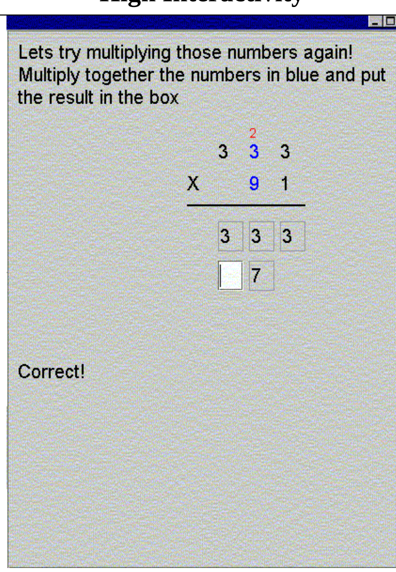
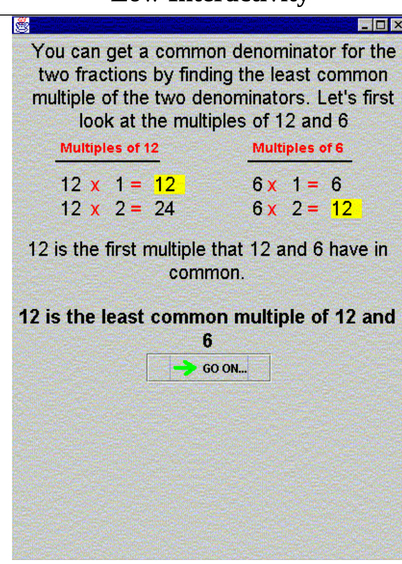
Symbolic/Procedural Hint High Interactivity	**Symbolic/Procedural Hint Low Interactivity**
	

Figure 4: Examples of hints differing in interactivity

To evaluate girls' reactions to the different types of hints, ratings from a survey were analyzed, in relation to gender and cognitive development. In a pre-test session, students' cognitive developmental stage was assessed via a computer presented battery of Piagetian reasoning problems (Arroyo et al., 1999). Students also completed a survey about their AnimalWatch experience, including questions in which they were asked to rate the helpfulness of the different types of hints that they saw. The results indicated that, not surprisingly, both boys and girls of lower cognitive development needed more hints to solve the problems. However, there was a strong relation for girls between their cognitive developmental stage and their views of how helpful the different hints were. In addition, hints that were highly interactive (i.e., structured) were rated by girls as significantly more helpful than less interactive hints, and were more effective (i.e., were followed by fewer errors in subsequent problems), whereas there was no relation for boys, see Figure 5. Overall, the results indicated that not only is adaptive feedback especially important for girls, certain specific types of feedback are preferred by girls, whereas boys do not appear to show such consistent preferences.

Several evaluation studies showed significant improvements in attitudes towards math (confidence, value, liking) after students worked with AnimalWatch (Beck et al., 1999). The goal was to assess the effects of working with AnimalWatch on girls' math confidence. With regard to students' confidence in math, analyses of variance comparing the pre- and post-test data from the Academic Attitudes Questionnaire indicated that working with AnimalWatch led to significant increases in students' math self concept (Figure 3).

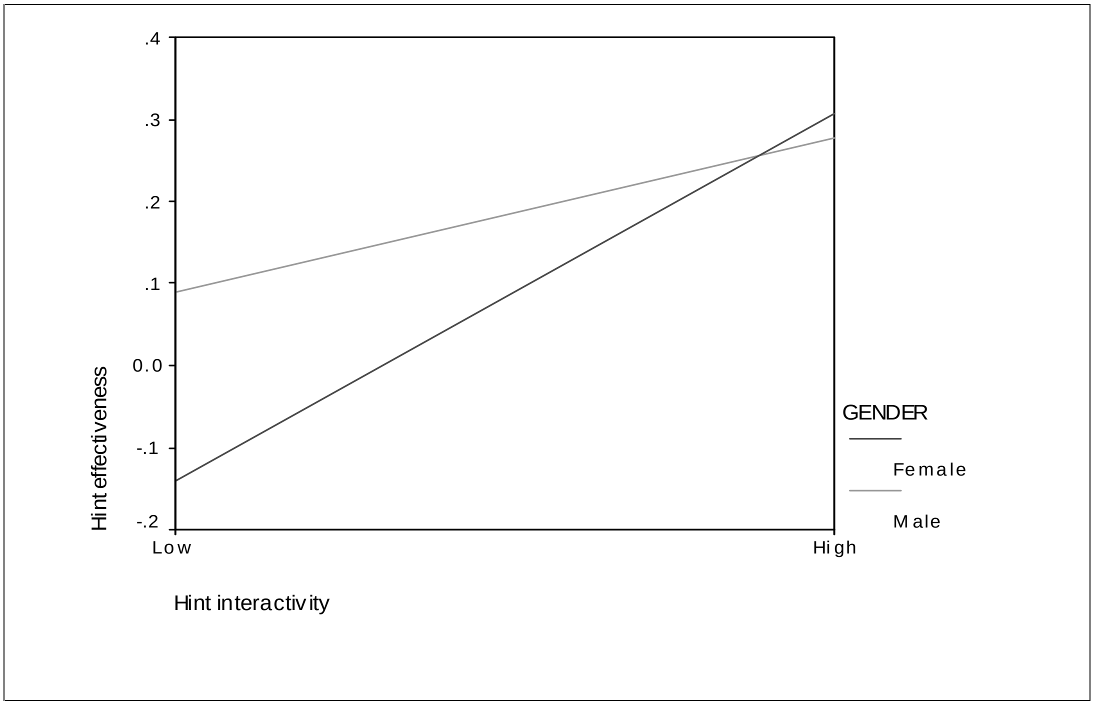


Figure 5: Gender differences in response to high and low interactive hints

Analyses of the AnimalWatch survey revealed that students generally rated their experience highly: Means range from 3.78 to 4.85 (on a 5 point scale) for questions such as "Would you like to use AnimalWatch again?," "When you made errors, did AnimalWatch give you enough help?," "Do you think the computer is a good way to learn math?." On the question, "Did you like working with AnimalWatch?," girls gave significantly higher ratings than boys (mean 4.50 for girls, 4.05 for boys).

4. Dissemination

Classroom teachers and teachers-in-training were involved in the design of AnimalWatch and in the evaluation studies. Workshops for the participating fifth grade teachers focused on gender equity in math and science, as did guest lectures to psychology, education and teacher training programs and three-hour workshops for student teachers.

AnimalWatch received high marks from the teachers, who rated it highly on such issues as appropriateness of math topics, sufficiency of help, ease of use, and fit to their curriculum. They also felt that working with AnimalWatch would help prepare girls for high stakes achievement tests such as the PSAT or the MCAS (a new state assessment test suite in Massachusetts), on which girls typically perform less well in math than boys. All the participating teachers volunteered their classrooms as sites for future evaluation studies.

Teachers responded very positively to AnimalWatch's ease of use and resilience (i.e., there is little that a student can do to "mess up" the computer and thus require teacher intervention). They were very pleased that it will run on any platform.

5. Current Research Issues

Our primary goal in the project is to help girls tackle increasingly challenging math learning while maintaining their confidence in their math ability. The critical mechanism is AnimalWatch's ability to immediately provide individualized adaptive feedback and to pace the difficulty of problems to avoid discouraging the student with repeated failures. In particular, we are now concerned with how rapidly AnimalWatch should "push" girls through the math curriculum. To address these issues, a mechanism that quickly and automatically estimates the optimal sequence and rate of problem presentation for each student is being evaluated. Another goal is to add an additional species, with background research and context construction. At the request of many teachers, we will add a user feature that would allow teachers to review the progress of individual students after each session with AnimalWatch.

An artificial intelligence learning mechanism that quickly and automatically estimates the optimal sequence and rate of problem presentation for each student is being evaluated. However, determining when a student is bogged down in problem solving is actually quite difficult, technically. First, the overall skill level of the student must be accounted for. If two students are given identical problems, the more skilled student will solve the problem more quickly than the less skilled student. Second, there are considerable individual differences in how quickly students work. For example, some students navigate the keyboard more quickly than others, some students have the multiplication tables memorized (more often, boys) while others prefer to use pencil and paper (more often, girls) etc. Any of these factors can impact the time required to solve a problem. Finally, the time required to solve a problem is a noisy variable. That is, if a student is given similar problems, he or she may take very different amounts of time to solve them. A small mistake at the beginning of the problem solving process can drastically impact the time required to solve a problem. All these issues are being investigated.

6. References

Arroyo, I, Beck, J., Schultz, K., & Woolf, B. P. (1999). Piagetian psychology in intelligent tutoring systems. *Proceedings of the Ninth International Conference on Artificial Intelligence in Education*, pp. 600-609.

Beal, C. R., Woolf, B. P., Beck, J., & Arroyo, I. (1999). WhaleWatch: Promoting gender equity in mathematics instruction through educational technology. Poster presentation at the *European Cognitive Science Society* annual meeting, Sienna Italy.

Beck, J., Stern, M., & Woolf, B. (1997). Cooperative student models. In *Proceedings of the Eighth International Conference on Artificial Intelligence in Education,* pp. 127-134.

Beck, J., Arroyo, I., Woolf, B. P., & Beal, C. R. (1999). Affecting self-confidence with an ITS. *Proceedings of the Ninth International Conference on Artificial Intelligence in Education*, 611-613, Paris, France.

Beller, M., & Gafni, N. (1996). The 1991 International Assessment of Educational Progress in Mathematics and Sciences: The Gender Differnces Perspective. *Journal of Educational Psychology,* 88, 365-377.

Berry, J., Wing, R. E., Crawley, A., & Beal, C. R. (2000, April). Collaborative learning with AnimalWatch: The impact of partner gender on girls' math achievement and attitudes. Submitted for presentation at the annual meeting of the *American Educational Research Association,* New Orleans LA.

Hart, D. M., Arroyo, I., Beck, J., Woolf, B. P., & Beal, C. R. (1999). WhaleWatch: An intelligent multimedia math tutor. Proceedings of the *International Conference on Mathematics/Science Education and Technology* (M/SET'99), San Antonio, TX. March 1999, pp. 565-570.

Stern, M., Beck, J., & Woolf, B. P. (1999). Naive Bayes classifiers for user modeling. Poster presented at the *Seventh International Conference on User Mode*ling, Banff Canada.

Acknowledgments

This work has been funded from two National Science Foundation awards from the Experimental Programs for Women and Girls program HRD 9714757. It has also received support from the University of Massachusetts and from the Frontier Regional School System and the Springfield School System. We acknowledge the extensive efforts of system programmer, David Marshall.