

# SOFTWARE SUPPORT FOR STUDENTS WITH ATTENTION PROBLEMS

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- Modeling pedagogical interactions

## ABSTRACT

Over three million students in the United States are affected by serious attention problems (ADHD), which often leads to poor academic performance and undermines their chances for success later in life. The goal of this project is to extend our intelligent computer tutoring system for mathematics to accommodate students with ADHD. The AnimalWatch software dynamically adapts instruction to support individual student needs and will help improve focus of attention, without causing distraction. The software will adjust instruction, both within a session and across multiple sessions, continually refining the accuracy of the individual student model. The primary focus will be on children with attention disorders; however, the addition of a model of student attention will benefit typical learners as well.

Evaluation studies will be conducted both in the laboratory using eye tracking equipment, and in the field in our partner public schools. Our deliverables include: 1) identification of attention issues and software interface features for learning activities; 2) determination of a model of attention required for reasoning about normal and special student-interactions; and 3) the design and development of models for dynamic response to students in an educational setting.

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## 1. INTRODUCTION AND GOALS

Extremely poor attention is a fundamental characteristic in children with Attention Deficit/Hyperactivity Disorder (ADHD), which affects more than 3 million children in the United States, as well as many adults (Nadeau, 1996; Hallowell & Ratey, 1994). ADHD is a serious concern as it “often continues into adolescence and adulthood, and can cause a lifetime of frustrated dreams and emotional pain.” (Neuwirth, 1996). “Antisocial behavior is likely to be troublesome for at least 20 to 45%” (Barkley, 1995, p.83). Students with ADHD often face considerable challenges to academic achievement. There is an urgent need for new educational techniques that are effective with ADHD students and that will also benefit typical learners.

To address this need, we are supporting the classroom learning needs of children with ADHD, by adapting an existing intelligent tutor to reason about the best way to accommodate a student’s attention problems during learning. The existing tutor, which has been shown to be highly effective with typical learners, is being expanded to include additional multimedia features and interface design functions to enhance interest and maintain problem solving focus in all learners, and particularly ADHD students. We are developing a model of attention to reason about the student’s current level of attention and to estimate his or her confidence and motivation, based on factors such as time spent, responses produced, success rate, and situational context. Evaluation studies with ADHD and typical learners will be conducted both in laboratory settings and in public schools, including detailed analyses of eye movements while problem solving; analysis of extensive problem solving data automatically collected by the computer as students work; and surveys and questionnaires from students and teachers regarding the effectiveness of the software.

Our target domain is mathematics learning. Mathematics is increasingly important in our technological society, but many students still perceive math learning to be overly difficult, unrewarding, and uninteresting. Students often report that they have trouble concentrating on mathematics, and the problem is particularly acute for ADHD students (Tobias, 1995). The AnimalWatch mathematics tutor has already been shown to be effective and engaging for students with a range of skills and characteristics. Incorporating a model of attention into AnimalWatch is predicted to enhance learning in all students through more effective computer modeling of individual students’ conceptual understanding and better

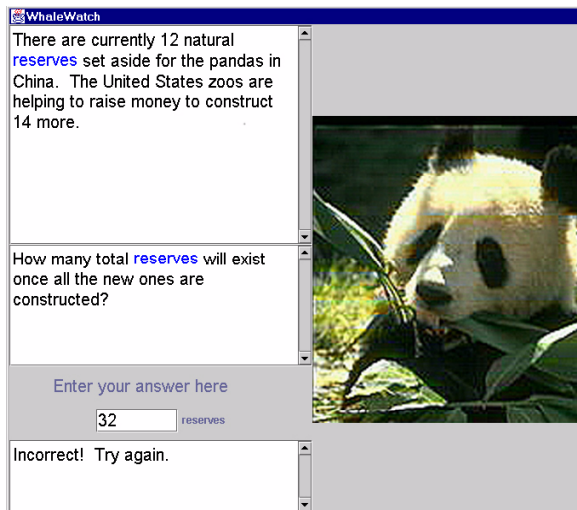
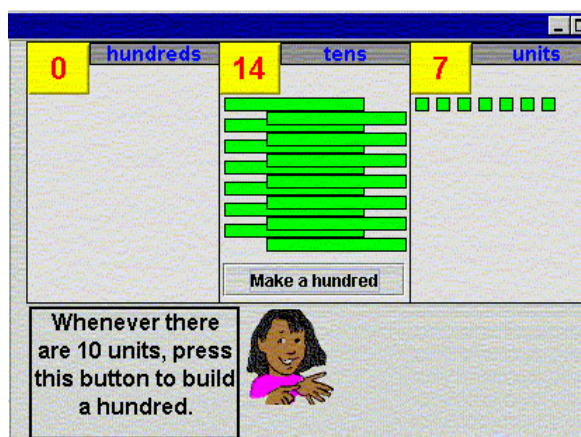


Figure 1. A Simple Addition Problem

selection of appropriate hints and instructional features. That is, adjusting instruction to accommodate the extreme case is predicted to benefit typical learners as well (Rafal & Robertson, 1995).

## 2. MODIFYING THE TUTOR FOR ATTENTION PROBLEMS

We are incorporating a model of student attention into AnimalWatch, the mathematics tutor for 10-12 year olds. In the present version of AnimalWatch, students enter a narrative about the ecology of endangered species



**Figure 2. Manipulatives for Teaching Addition.**

(e.g., Giant Panda; Right Whale; Przewalski Wild Horse), and solve mathematics problems in a meaningful context, Figure 1. Problems are selected and customized for each student through the student modeling function of AnimalWatch. The student model currently uses information about student characteristics such as level of cognitive development and gender, as well as the student's ongoing problem solving performance, to estimate what the student understands and where he or she needs help, to select problems at an appropriate level of difficulty, and to present hints, instruction and help features that are tailored to the student's needs and abilities (Stern et al., 1996; Hart et al., 1999). Hundreds of procedural and declarative hints are available and screen manipulatives, such as "Cuisenaire

rods" provide students with concrete demonstrations of specific mathematical skills, Figures 2 & 3. Procedural support breaks a problem into manageable steps and guide the student towards a solution.

AnimalWatch reasons about student performance and learning style and then determines the appropriate problem solving support for each student. The student model is continually updated and revised as the student works. In previous field studies, students have shown significantly enhanced math learning and motivation after working with AnimalWatch; also, the benefits increased as the student model was extended to incorporate more detailed information about individual students (Arroyo, 2000; Beal et al., 2000). Evaluation results show highly adaptive feedback is especially important to girls: When students worked with a version of AnimalWatch with the adaptive feedback "turned off," girls were much more negatively affected than boys (Beal et al., 2000; Arroyo et al., 2000). We identified the specific types of hints and help that are most beneficial to girls, particularly girls at different stages of cognitive development. Hints varied in the degree of interactivity required from the student: hints that are highly interactive are also highly structured and walk the student through the solution process in incremental steps.

Results indicate that both boys and girls of lower cognitive development needed more hints to solve the problems. However, there was a strong relation for girls between cognitive developmental stage and girls' 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. 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.

We observed significant improvements in attitudes towards math (confidence, value, liking) after students worked with the AnimalWatch tutor. With regard to students' confidence in math, results indicated that working with AnimalWatch led to significant increases in students' math self concept [Beal et al., 2000].

AnimalWatch already adapts its instruction very effectively for a range of students, and has been used in more than a dozen classrooms with students of various skill levels. Yet there is room for improvement in the realm of maintaining a student's attention. Many educational methods currently used in classroom teaching to support children with attention problems, including reducing off-task interruptions, making on-task activities more interesting, eliminating distractions and providing organizational support to help children complete activities, can be incorporated into AnimalWatch. Specifically, for ADHD learners, we are:

1. Increasing the variety of problem presentations. Problem repetition is annoying to typical learners but is particularly disruptive to students with attention difficulties: "Recent research suggests that providing more stimulation and variety can improve the performance and behavior of students with ADHD. [The teacher should] alter the type of assignment, the activities involved, or even the color of the paper used." (Office of Special Education and Rehabilitative Services, United States Department of Education.);

2. Ensuring that all problems are clearly organized and that the screen layout is easy to follow; ADHD students appear to need clearer, more dynamic screen cues to aid processing;

3. Allowing the student to skip material in presentations that is not motivating; if the student model hypothesizes attentional lags, a shift in context, problem topic, or target animal may revive interest and attention;

4. Using concrete concepts that have immediate significance over more abstract, symbolic problem representations;

5. Dividing large blocks of text into smaller paragraphs that require less attention; the existing AnimalWatch tutor assumes grade-level reading proficiency;

6. Eliminating distracting elements; although some screen elements can be motivating, others can be disruptive.

7. Increasing rates of reinforcement and feedback; although all children benefit from positive feedback about their work, this is particularly important for students with attentional problems.

8. Incorporating problems on organization and planning: children with ADHD have particular trouble with these skills. For example, more problems on the computation of departure times, given a deadline and travel times, will be added.

These modifications are consistent with established techniques for addressing the needs of ADHD students in the classroom (Hallowell & Ratey, 1994; Barkley, 1995; <http://www.add.org/content/school/list.htm>). Specifically, dynamic adjustments of problem difficulty and degree of scaffolding are particularly helpful for students with attentional difficulties, but are unrealistically demanding for human classroom teachers. Also, computers are ideal for presenting highly structured problem interfaces and special visual and sound effects, characteristics that are especially important for ADHD students. (Barkley, 1995).

### 3. EXAMPLE INTERACTION

Consider a hypothetical student “Martin” who has been diagnosed with ADHD and is in the school computer lab with the rest of the class. AnimalWatch immerses Martin in a scenario about working with Giant Panda researchers at the Wolong Research Station, in China.

Martin is overwhelmed by the length of a word problem and begins moving the cursor randomly, clicking on irrelevant parts of the screen. The computer eventually determines that the student is not paying attention and attempts to re-engage Martin’s attention. An animated Panda appears on the screen and an audio prompt is presented, “Let’s look at this another way.”

The word problem is now presented in a graphical format, broken into shorter segments. Martin reads “Your trip to China is going to be very expensive” in one screen and “you will need to raise some of the money yourself” separately, reducing the number of words appearing on the screen at one time. He then presses the continue button. A graphic image shows a child washing a car for \$15 and a child mowing the lawn for \$18. The question asks: “If you washed your neighbor’s car and mowed her lawn, how much would you save for the trip?” The use of multiple screens to present this problem is more time-consuming than the original textual format, but is required because Martin could not focus on that much text at once.

Martin understands that he should add the two numbers, but often forgets to carry digits to the left. Working on scratch paper, Martin computes  $8 + 5 = 13$ , but then adds  $1 + 1$  and writes 2 to the left of the 3, forgetting to carry the 1 to the ten’s column. He types the number “23.”

Now the computer leads Martin through the problem step by step. First, the computer asks Martin to add  $8+5$  and enter the result. Figure 3 shows the screen format, although the numbers are different. Martin types “13,” as he did on paper. The computer rearranges the numbers to show how the digit is carried and Martin sees he has to add  $1+1+1$ , and completes the problem.

In subsequent problems, AnimalWatch will present problems in a more structured fashion, as it has inferred that Martin needs smaller steps and more reinforcement than many students. These adaptations improve the computer’s ability to teach Martin, but for other students a different selection of adaptations are preferred.

### 4. EVALUATING ADAPTATIONS

We are conducting four experiments to evaluate the impact of incorporating our model of attention into AnimalWatch. The first two will be conducted in laboratories at the University of Massachusetts campus by psychologists experienced in working with children with ADHD (Royer & Cisero, 1993; Pitonak & Royer, 2000). The third experiment will be a field study conducted in a large public middle school. The fourth experiment will

involve the use of data from hundreds of student users of AnimalWatch, including ADHD students, to modify the software and to evaluate its performance for students with a wide range of attentional skills.


Experiment 1: Attention, learning and motivation in ADHD students using AnimalWatch. The goal of this experiment is to identify the precise differences in problem solving between typical students using AnimalWatch for mathematics learning and students with ADHD. The study will include 12-16 ADHD students, aged 10-14 years, and 12-16 typical learners of the same age. Parents of ADHD volunteers will complete a short questionnaire including basic data (age, gender) and pertinent data on attention deficit, including diagnosis date, therapy, medications and school-based intervention plan. Students will work at the computer with the present version of AnimalWatch math system, and complete a 20 minute standard survey instruments regarding their math motivation and their opinion of AnimalWatch. Data regarding the student's math problem solving are automatically collected by AnimalWatch; these data include estimates of the student's mastery of specific math concepts (e.g., procedure for

**Having Problems Adding?**

One step at a time... Add each column of numbers. I will do the carrying for you.

$$\begin{array}{r} 1 \\ 375 \\ 315 \\ \hline 10 \end{array}$$

Incorrect! Try again.



**Figure 3. Customized Hint**

effective with ADHD learners).

Experiment 2: Patterns of eye movements in math problem solving while using AnimalWatch. Our model of attention suggests that ADHD students have particular difficulty with planning and sequencing in problem solving, and that transitions from one problem solving step to another (e.g., after using the least common multiple to make denominators equivalent, you must also recalculate the numerators) are especially likely to lead to distraction and problem solving failure (Brickner, 1970; Gluck et al., 2000). It is important to identify ways that students with attentional difficulties process information on the computer screen, including their ability to move from the image or graphic on the right side, to the top of the screen (where the background for the word problem is introduced), the problem area in the upper third, the hint area on the far right, and the answer area in the lower left. It may be especially challenging for students with attentional difficulties to grasp the spatial organization of the problem and to navigate visually to the appropriate area of the screen at the right time. Although longer time to solve the problem (time to solution is one of our standard dependent measures) would be one indication that this is the case for ADHD students, it is not particularly precise; a student who takes more than 3 minutes to enter a first answer to a simple addition problem may indeed be "lost on the screen" and looking at the wrong thing, but he or she might also be chatting to a neighbor in the computer room or staring out the window. In order to address these issues, we will use eye-tracking equipment to record the location of a student's current focus of attention. By monitoring eye movements, we will determine when students are not paying attention, and assess the relation of attentional lapses to factors such as the difficulty of the problem selected by AnimalWatch (e.g., perhaps the level of challenge was escalated too quickly) and screen design issues (e.g., a hint has appeared on the screen but the student has not looked at that area).

finding the least common multiple), probability of errors in problem solving, time required to solve problems, number and type of hints required, rate of progress through the curriculum, and effectiveness of different types of hints in terms of subsequent problem solving success.

We predict that typical learners will outperform ADHD students in problem solving; ADHD students will spend more time per problem to achieve success; time spent per problem will be more variable and less predictive of success for ADHD students; "careless" errors will be more prevalent for ADHD students; and that the success rate will not climb as rapidly as is typically observed for students without ADHD. In addition, we predict that ADHD students will report lower math motivation and less enjoyment of AnimalWatch. The results of the first study will help to identify the areas of the curriculum that are especially in need of modifications to maintain attention and motivation in ADHD students, as well as to sort out the types of hints and feedback that seem to be most strongly correlated with problem solving success in this population (e.g., based on our prior work with children of varying levels of cognitive development, we predict that hints that are more structured will be especially

Eyetrackers require levels of attention and sustained cooperation by the user (e.g., fixed head position) that are likely to prove difficult for children at best, and highly stressful at worst. Therefore, in this study we will recruit 16-20 adult learners with ADHD from the Learning Resources Center at the University of Massachusetts campus, and 16-20 typical adult learners from the Psychology Department participant pool. Each student will participate in a one-hour session during which he or she will work with AnimalWatch while eye movement data are collected. Problem solving data will be automatically collected by the system, as outlined in the first experiment. We predict that ADHD students will show less efficient visual navigation of the screen and correspondingly longer solution times and higher error rates. In addition, we will be able to identify the precise points in the problem solving process where the ADHD student loses focus, and the specific areas of the screen layout and problem presentation design that need improvement (e.g., when a hint is presented, ADHD students may need a visual cue to shift their attention to the hint area).

Experiment 3: The impact of an enhanced AnimalWatch system on ADHD and typical learners. By incorporating an estimate of student attention into the student model component of AnimalWatch, the system's ability to select appropriate problems and hints should be significantly enhanced. To evaluate this prediction, we will conduct a field study at one of our partner schools: a large, urban, diverse middle school in Springfield Massachusetts which serves nearly 700 students aged 10-14. We estimate that between 5 – 10% (35-70) of the students have a diagnosis of ADHD. Students will come to the school computer laboratory for 3-5 sessions over the course of 1-2 weeks, as part of their regular mathematics coursework. Different versions of AnimalWatch -- one with and one without the attentional component in the student model -- will be installed on different machines in the laboratory. The baseline AnimalWatch system will contain all of the media and content, but only the enhanced system will reason dynamically about the student's current level of attention to help focus attention. Because instruction is already individualized, students will not be able to detect which version they are using; in fact, past studies have shown that they do not even realize that there are different version. Students will not have to be "labeled" as ADHD in advance; rather, the system will continually estimate the student's level of engagement and adjust its teaching accordingly to produce optimal problem solving. Problem solving data will be collected and analyzed as described earlier. Predictions are that ADHD students will initially perform less well than their peers who are typical learners; however, the gap between ADHD and typical learners should decrease for those using the enhanced version of AnimalWatch. In addition, we predict that ADHD students who work with the enhanced version will show higher math motivation and liking of AnimalWatch, compared to those who work with the present version. We expect that students with a greater ability to focus will be less affected by the changes we make, while students who have more difficulty concentrating should show larger increases across a variety of measures (problems solved, how much they like the tutor, etc.).

Experiment 4: Training AnimalWatch to predict and forestall attentional lapses in problem solving. Many of the modifications suggested by our model of attention, such as increasing the variety of problem templates, clarifying the interface design, adding screen cues, and adding reward features such as video clips or animation, etc., seem as though they should be helpful to all learners, not only students with ADHD. If so, the enhanced version of AnimalWatch should be effective for typical learners in Experiment 3, above. In this case, everyone could use the enhanced version. However, it is also possible that adaptations designed with the ADHD student in mind may prove disruptive for other students (Jonassen & Grabowski, 1993). Mayer and colleagues have found, for example, that the addition of video clips or narration designed to "spice up" a computer based lesson can actually reduce student comprehension and memory for the content (Mayer & Morenson, 1998). Or, a highly interactive system may maintain students' attention to the screen, but may unnecessarily delay students who already have strong attention skills and interfere with their progress through the curriculum. It is also possible that what is effective for a particular student may vary over the course of a session or over several sessions, as the student progresses through the curriculum and gains or loses motivation. Implementation of simple and coarse-grained adaptivity to different attention levels would be sufficient if a single attention model was appropriate for all students, or for easily distinguished groups students. However, attention is a complex non-linear process and we expect the system to require integrated reasoning about context and attention abilities in order to respond dynamically.

To accomplish this goal, machine learning algorithms will be added to the student model of AnimalWatch in order to continually update and adjust its estimate of the learner's attention and motivation. That is, the performance of hundreds of students in the past (already recorded by AnimalWatch) particularly those with similar learning profiles, as well as the learner's own past and current performance, will be used to train the system to select the teaching strategies that are most likely to be effective with this student at this point in time. Predictions generated by the machine learning algorithms will also be tested with the large dataset.

## 5. SUMMARY

Ensuring that all children are appropriately challenged in a domain requires sophisticated student models and powerful reasoning capabilities. To achieve this goal for ADHD students, the AnimalWatch mathematics tutor will be enhanced to incorporate estimates of student attention while solving mathematics problems. We have already developed methods for creating sophisticated models of student capabilities (Eliot & Woolf, 1996; Beck et al., 2000) which will be extended to include estimates of attention and mechanisms to prevent loss of attention, when possible, and to regain and redirect the student's attention when needed. The enhanced functionality and increased adaptivity of AnimalWatch will benefit typical learners as well as those with ADHD. This research will generate fundamental insight critical to the successful deployment of attention models. In.

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