Problem Posing in AnimalWatch: An Interactive System for Student-Authored Content

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Abstract

Bringing users into the process of content development may help to reduce the time and cost associated with tutoring system development, and may benefit users by deepening their understanding of the domain. We describe a pilot effort with middle school students who successfully authored word problems for the AnimalWatch intelligent tutoring system for Grade 6 math, and the design and pilot testing of a new module for user-authoring of AnimalWatch problems.

Introduction

The AnimalWatch tutoring system

AnimalWatch is a web-based intelligent tutoring system that provides instruction in pre-algebra mathematics, appropriate for students in Grade 6 (ages 10-12). The system focuses on word problems about endangered species, with problems forming an episode-based narrative with environmental science topics. For example, students can solve problems about the Right Whale that involve a virtual trip on a research boat in the North Atlantic, followed by a virtual visit to a beach in Argentina where Right Whales migrate. If the student needs help solving a problem, a menu of multimedia resources can be accessed through the "help" icon. Help resources include worked examples, interactive explanations, and short videos about the different math skills, e.g., how to find the average, median and mode. The word problems that are presented to a particular student are selected on the basis of an artificial intelligence algorithm that maintains an estimate of mastery for the target math skills in the system. Mastery estimates are updated as the student works.

AnimalWatch currently includes almost 1000 word problems, with virtual adventures available for the Giant Panda, Mongolian Takhi Wild Horse, White Shark, Right Whale, and California Condor. A large number of problems per species is required so that the problem selector can find problems for any math skill that the student may be working on. Thus, for example, two students may be working on the second Right Whale adventure episode, but one may be viewing problems involving division, whereas the other may be solving problems involving addition of fractions with unlike denominators. Even with a large number of problems, the problem selector can "run out" if a particular student makes errors on multiple problems involving a particular skill. The system includes at least four word problems per species, per skill and per level of difficulty. However, if a student has not mastered a skill, the system may have to choose an easier or more difficult problem. In the original version of the system, post-hoc analyses of the problem selector's performance suggested that students were not pushed through the curriculum as quickly as intended, in part because when there were no problems left for a particular species, skill and difficulty level, it would fall back on easier material (Arroyo, Murray, Beck, Woolf & Beal, 2003). Thus, even with quite a large number of word problems available for the problem selector to work with, content issues constrained the system's pedagogical performance.

The challenges of providing sufficient content are not unique to AnimalWatch. Content authoring has long been recognized as a major bottleneck for the development of tutoring systems. Creating materials is time-consuming and costly, and the results must be reviewed to ensure accuracy. Experts are difficult to locate, and may not be available to participate in development. It is also not always clear that content created by experts will match students' interests.

One potential strategy would be to involve end-users in the development of content for tutoring systems. The original AnimalWatch word problems were written by project members, using scientifically accurate information from informal learning institutions (e.g., New England Aquarium, Zoological Society of San Diego). More recently, we have been developing procedures and tools to allow middle school students to write word problems that will be included in the AnimalWatch tutoring system, and to allow teachers to review, provide feedback and approve

problems created by their students. Other efforts include the work of Arroyo (Arroyo, Schapira & Woolf, 2001; Arroyo & Woolf, 2003) who developed a web-based environment for teachers and students to author word problems. Another recent effort to involve students in authoring is presented in Hirashima, Yokoyama, Okamoto and Takeuchi (2007) who created an interface for young students (second graders) to compose problems by moving virtual cards containing sentences into the appropriate order to represent a coherent equation and solution. An evaluation study indicated that students who worked with the system showed significant improvements in their problem solving. However, in this study, the components of the problems (individual sentences) were provided for students to arrange, rather than being directly authored by the students themselves.

Problem posing

In addition to the goal of accelerating content development, other reasons to involve users is that the activity may have a valuable pedagogical role in terms of deepening their understanding of the domain, engaging them in critical thinking skills and providing a medium to practice their communication of math and science concepts. In particular, in the area of mathematics education, "problem posing" has been recognized as a promising practice for helping students. Problem posing is defined as involving students in the process of generating new math problems from available information, or searching out information and using it to construct new numerical relation (Brown & Walter, 1990). The practice is thus distinct from the much more common activity of requiring students to solve problems that have been prepared by others (teachers, textbooks).

Researchers and practitioners offer three broad lines of argument for the utility of problem posing: First, creating problems is argued to be analogous to the ways that scientists and mathematicians actually work, and is thus consistent with recent emphasis in education on self-directed inquiry learning. Second, problem posing activities may help students develop their metacognitive skills, including their ability to monitor what is understood and what is not yet clearly defined or explained. By providing students with practice in reflecting on the components of a problem, assessing the quality of a problem, and trying to explain a solution for the problem, students may gain new insights that would in turn help their own problem solving. Third, teachers have reported that problem posing activities appear to increase student engagement and may even reduce math anxiety because students who write problems have a stronger sense of self confidence (English, 1997).

To date, there have not been systematic studies of the impact of problem posing on students' problem solving skills. Some prior work indicates that students typically solve problems better than they write problems, however, this may be due to lack of familiarity with the problem posing activity (Cai & Juang, 2002). Other studies suggest that problem posing can be challenging to implement in the classroom, especially for novice teachers (Crespo, 2003; Verzoni, 1997). Thus, interest is growing in developing technology-based tools that could structure and support problem posing as a student activity (De Corte et al., 2003).

The present project is designed to develop features that will allow students to write word problems that can be used in the AnimalWatch tutoring system, both to assist with content development and, ultimately, to provide support for the integration of problem posing into the mathematics classroom. We first outline the paper-and-pencil activities used to develop the problem posing activities, followed by the design of the AnimalWatch problem posing module.

Student authoring activities

Small-group problem posing

Participating students (N = 24) were enrolled in a summer academic preparation program held on the university campus. Students attended the program for four hours each Saturday, with two hours devoted to math instruction. Students used AnimalWatch for part of the program. In the final two sessions, students participated in a problem posing activity. The first author led a 20 minute introductory lesson about problem posing, before students were asked to form small groups (4 students per group) and to write problems about the California Condor.

Groups were provided with paper packets containing background information about the condor, including facts, graphs and tables with accurate and authentic numerical information. Students were also given paper templates that included space for a word problem, and areas where students were asked to write the math skill the problem required, the numbers involved, the equation, and the answer. Each group attempted to complete at least four problems. An example is shown in Figure 1.

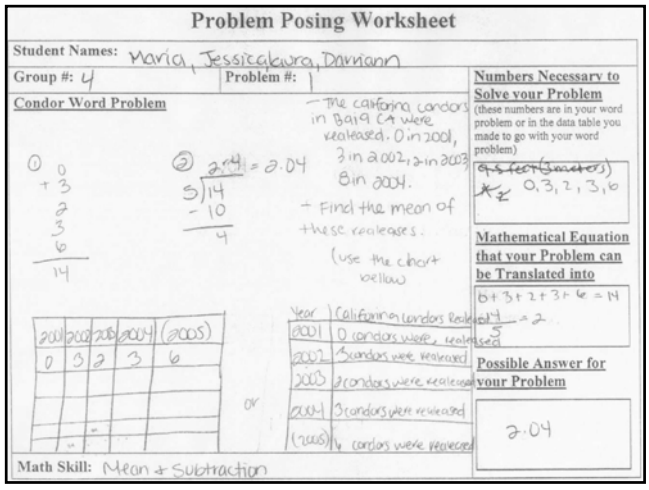


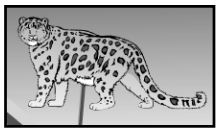
Figure 1. Paper based problem authoring template

After the session, the problems were photocopied onto a "rate this problem" template. In the second session, the word problems authored the previous week were distributed to different students, and students were instructed to read the problems and complete the ratings. Ratings included responses to questions about whether the problem could be understood, could be translated into an equation, was interesting, and should be considered for inclusion in AnimalWatch. Comments could also be added, along with an attempted solution.

Review of the problem ratings sheets indicated that students were able to make reasonable judgments about problems. For example, a problem authored by one student that consisted only of the sentence, "Condors can soar on warm thermal updrafts" followed by a series of scribbled numbers was rated by other students as not understandable or interesting, and elicited comments along the lines of, "What is the question???" The largest category of comments consisted of suggestions to put information into a table or chart (e.g., long sentences about the number of condors released into the wild over the years) and remarks that a problem was "too easy" (e.g., if a condor can fly 50 miles a day how many miles could it fly in 14 days?). Students were mostly generous with praise ("Cool" "awesome" "nice job") although there were occasional critical comments ("I can't understand a word").

The activity, although highly exploratory, provided some indication that student problem posing for tutoring systems was feasible and potentially productive: One session resulted in over 90 word problems authored by students. Of course, there was considerable redundancy in the content because students all worked with the same six-page information packet. Also, not all problems were coherent, complete or interesting to other students. Yet the activity demonstrated that students could produce useable content; about 40 problems are now being added to AnimalWatch. In addition, students appeared to find the activity engaging, once their initial bemusement at being asked to write problems instead of solve them had passed.

The student-authored Snow Leopard adventure



A middle school student subsequently volunteered to develop problems about an additional endangered species, and choose the Snow Leopard. Using the template piloted in the summer study, she authored two complete episodes of 30 problems each: The first episode included problems with basic information about the species, habitat, and threats to its survival; the second episode included problems about a visit to the Los Angeles Zoo, home to a famous exhibit with several snow leopards. The student authored two text hints for each problem, in addition to linking the problems to the existing multimedia help resources. She also used the Internet to locate images posted by private individuals and contacted them by email for permission to include the pictures in her word problems. An example of a Snow Leopard problem is shown in Figure 2.

The student's problems did require adult editing, particularly to ensure that the scientific content remained accurate. For example, in one case the student wrote a problem about a large number of cubs born in a particular den site and then had to clarify that because snow leopards are solitary, the total would have accumulated over a long

Figure 2. Student-authored problem about Snow Leopard

time. However, the investment in editing the student's work was about two hours, whereas it would have taken two days for even a skilled adult author to create 60+ word problems. The Snow Leopard project thus provided additional indications that students could create content that would be usable in the ITS, if not immediately, with a fairly modest investment on the part of the system developers. The problems were added to AnimalWatch and used by other students in the subsequent academic year. Many seemed impressed that another student had contributed material to the software.

AnimalWatch problem posing module

The paper-and-pencil activities provided some indication that students could author word problems, given that they were provided with resource materials and with the use of the authoring template to help structure the activity. The next step was therefore to build a problem-posing feature into the AnimalWatch tutoring system, so that students could access materials and author problems online.

The result is a new feature that allows the student to shift easily from solving word problems in the original system to the problem-posing module from the main menu screen, by clicking the problem-

posing icon. Students can then choose an endangered species. Information about endangered species, including facts (habitat, characteristics, diet, survival threats, etc.) and current status (vulnerable, threatened, endangered, etc.) was incorporated into the AnimalWatch Problem Posing expansion through the online resources of the World Conservation Union (IUCN) available for fair educational use. Students can browse a list of species, or search for a species by name or by its habitat (biome). For example, a student may select the grasslands biome, then view a list of animals associated with the habitat and choose the cheetah (Figure 3). Animals may be associated with multiple biomes (e.g., the cheetah lives in grasslands and desert).

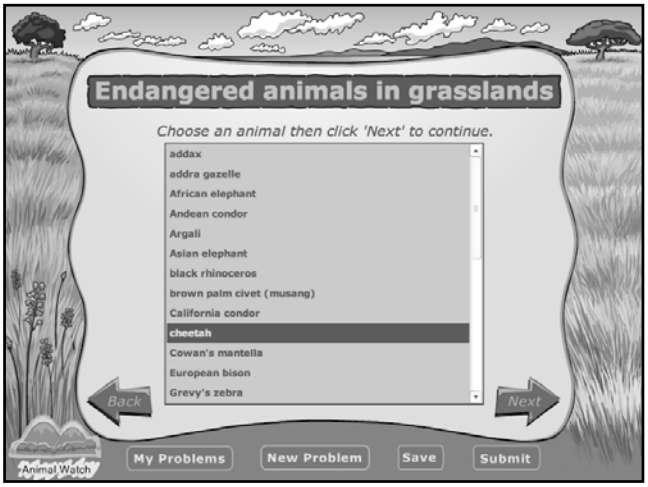


Figure 3. Students can browse and select endangered species linked to biomes

After choosing a species, the student moves on to a math word problem authoring template page, which includes six areas to be completed. The page includes a box where the student can type a problem. An "Animal Facts" link opens a page with information imported from the IUCN's Redlist of Threatened Species™ database. For example, the facts about the cheetah include the information that the cheetah can run up to 87 kilometers per hour. The student might decide to write a problem requiring the conversion into miles per hour. The student can type the text of the problem into the problem area, as well as break up the problem into pieces to help them think critically of it and thus help lead them to greater accuracy. For example, they must choose the math skill involved in the problem (skills are defined in relation to state curriculum frameworks), list the numbers used in the problem, write the equation for the problem, provide the answer, and list the units associated with the answer (Figure 4).

After completing these areas, the student can preview the problem, accompanied by one of the images available in the IUCN database, and then save the problem, submit it for teacher review or continue to edit it.

Of course, writing problems is only part of the authoring process. Student-created problems will need review and editing before they can be used in AnimalWatch, in terms of language, interest, and mathematical accuracy. For example, students may not necessarily recognize the math skill that their problem actually involves (e.g., finding the cheetah's speed in miles per hour involves the multiplication operation but the skill as defined by the state standards is "unit conversion"). Also, it is important to include a human check of the student-generated content for age- and classroom-appropriateness. The system has been designed so that, after completing a word problem, the student must therefore submit it to the teacher for review and approval. Upon teacher approval, an AnmialWatch project member must also approve it before the problem is made available for other users to solve in AnimalWatch. Teachers can add comments or edit the problems directly. Students can access all of their problems and view the problems' status at any time through a problem manager: saved, submitted for approval, approved, and problems for which the teacher has requested revisions.

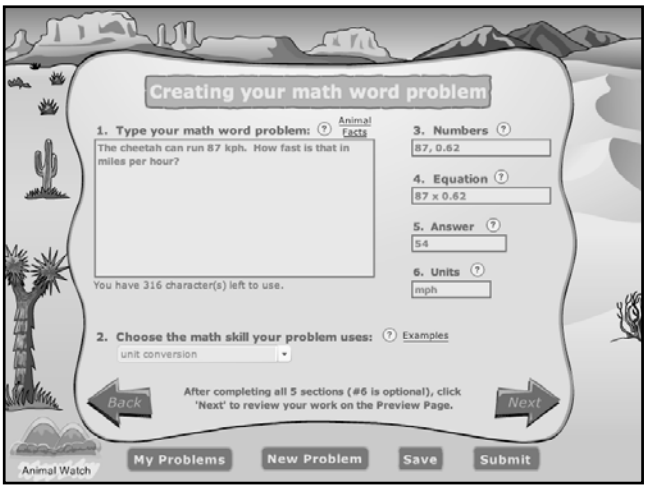


Figure 4. Computer based math word problem authoring template

The system provides considerable structure for the process of content development: The use of templates ensures that the student must complete the components that are required for the problem to be included in the ITS. By linking AnimalWatch with content databases (IUCN) students can access accurate, up-to-date factual information. The system also provides students with professionally-created digital artwork, such as the biome templates.

Usability study

We asked four middle school students to work with the problem posing feature, in a preliminary test of feasibility. Students came to the laboratory and worked with the AnimalWatch problem posing system for one hour. Their interactions with the interface were captured with screen

recording software. They then completed a brief survey about their reactions to the system.

Students successfully authored multiple problems using the system. Students appeared to be highly engaged with the activity, particularly with exploring the various endangered species that were available through the IUCN database listings. The most significant challenge appeared to be providing students with enough information to work with. Although the connection to the IUCN database of factual information ensured that information was current, there were still some endangered species for which little or no information was available (or, the information did not include numbers that the student could use to create a word problem).

The survey results indicated that the students had a positive response to the system. Students gave high ratings to survey items "Did you enjoy this exercise?" "Would you like doing this as part of your math class?" "Does writing problems help you learn math?" and "Was it interesting to learn about the animals?". However, only two (50%) of the students agreed that their teacher would use the system as part of math class.

Comments about what students did not like about the system all focused on the lack of images for some species, and on the poverty of descriptions for some animals. One student suggested that the navigation icons needed to be bigger. Comments about what students liked about the system were, "It was a fun way to learn" "It was fun and I don't like math and it helped" "We get to learn about math and science in a fun way" "I learned that there is something called an orange-footed pimple-back mussel".

We are currently reviewing the problems that students authored during the pilot study but one preliminary conclusion is that students wrote problems involving math skills that were relatively easy, e.g., addition, subtraction, multiplication and division, whereas their classroom work focuses on fractions, rational numbers and pre-algebra. It is possible that, if students worked longer with the system, the authored material would align with the material that they are studying. However, prior work suggests that students' authoring lags behind their own problem solving skill (Cai & Huang, 2002). Thus, additional scaffolding may be required to help students develop problems that involve skills in their "Zone of Proximal Development", meaning topics that they are consolidating through practice and instructional support (Brown, Ellery & Campione, 1994).

Next steps

The goal of adding problem posing into the AnimalWatch tutoring system clearly requires additional development and user testing. More specifically, we still need to learn if the technology-based system provides enough support for teachers to integrate the activity into the classroom successfully. Therefore, we still need to establish if teachers can provide students with sufficient feedback on their word problems, if the technology makes it easy enough for them to do so readily and if students respond to the feedback well enough to produce useful word problems. Furthermore, our current design of asking students to break their problem into parts not only leads them to analyze it but may eventually allow us to implement machine checking of their work and allow us to investigate providing the student with feedback prior to teacher feedback.

Some students also seemed doubtful that their teachers would be willing to incorporate problem posing into the math class, suggesting that the system would benefit from the additional of professional development materials to help practitioners understand its objectives. In addition, it will be important to learn if problem posing does deepen students' understanding of the target math content, as suggested by practitioners. AnimalWatch includes integrated pre- and post-test assessments that can be used as outcome measures, and we will be investigating the impact of the new problem posing feature on student performance.

One overall goal of the project is to learn if users can help to reduce the content development bottleneck. Even with the use of large-scale database resources, we found that providing enough content to work with remained a challenge. A related issue is the need to locate a source of images and video to accompany students' problems. Prior work indicates that although the images in AnimalWatch are not essential to the math activity, they serve a strong motivational function. Students are also highly sensitive to image repetition, meaning that each image can usually only be used once. Yet images of rare and endangered species are limited in quantity and often owned by professional wildlife photographers, meaning that they are not available for educational use. We are currently investigating several sources that may provide images for fair educational use. Another option is to add a feature that will allow students to upload their own drawings, photographs or video, e.g., taken on a visit to a zoo or nature park. For example, the student who created the Snow Leopard adventure added her own digital photos from a trip to the San Diego Zoo, including a short video clip of the leopard's hoarse call.

Another long term goal of the project is to study the work flow of students. Because AnimalWatch's Problem Posing component is a closed system (i.e. all information gathering and input is embedded) we will be able collect data on the order of processes the student takes and what their input looks like at measured intervals of each problem's creation as we further develop this system with the goal of capturing a more detailed view of the student problem solving process and common strategies used in order to better determine points of intervention and support

as well as feedback that may support critical thought and the expression of math and science concepts. Currently, the project only saves a new snapshot of student work when the student saves or submits the work providing us with limited and inconsistent time intervals of the evolution of their problem and an unclear picture of which information gathering and input steps were taken first, second and so forth. Additionally, because we provide students with a closed domain of facts to work with, we may eventually be able to include machine checking of the appropriateness of their problems' content in addition to machine analyses for consistency of the components of their problem.

To summarize, the goal of the project is to support young users' involvement in the process of content development, for both pragmatic and pedagogical purposes. The system described here was developed on the basis of pilot testing with students using paper and pencil materials, showing that students were able to create content now being used in the AnimalWatch ITS. The authoring system was successfully pilot tested with students who gave it generally positive reviews. Additional study will be required to evaluate the impact of the system on students' mathematical problem solving skills.

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