Proceedings of the 19th International Conference of the Society for Information Technology and Teacher Education, Las Vegas, March 2008, in press.

Working memory and math problem solving by blind middle and high school students: Implications for universal access

Carole R. Beal & Erin Shaw
Information Sciences Institute
University of Southern California
United States
cbeal@isi.edu, shaw@isi.edu

Abstract: Math achievement tends to be low for blind students, relative to other academic subjects. The project is investigating how blind students solve math word problems varying in text length and grade-level readability, in the context of an existing web-based tutorial. Text-to-speech software will allow blind students to access word problems in audio format. Replay actions will be used to track blind students' processing of word problem texts varying in number of words and grade-level readability. Results will be used to adapt the software to select math word problems that are appropriate for blind students.

Introduction

Achievement in math by blind students tends to be poor relative to performance in other academic subjects. Blind students face multiple challenges in math problem solving, including gaining access to the problem information, mapping the problem information to the appropriate representation, and providing the resulting answer. Adaptive interfaces can help make math problems accessible, and recent innovations in interface technology have provided new options for students with severe visual impairments (Chen, 2005; Walker, Lindsay & Godfrey, 2004; Yesilada, Stevens, Goble, & Hussein, 2004). Yet there has been relatively little research on the cognitive and motivational processes involved in the intervening phase, specifically, whether students without vision differ from their sighted peers in their ability to identify what the problem is asking, what operation is involved, to construct the corresponding equation, and to persist towards the solution when the initial attempts do not lead to success.

Our project focuses on mathematics problem solving processes in students who are congenitally or adventitiously blind, meaning that they have little or no vision, and who are functioning at or near grade level. We recognize that this is a focused population. For one thing, although visual impairments are relatively common around the world, functional and total blindness are relatively low-incidence disabilities in the United States, and are more common among adults than children. In addition, in many cases children who are blind also have other disabilities that may limit their achievement in school. However, rates of childhood blindness have been rising in recent years (Steinkuller, Du, Gilbert, Foster, Collins, & Coats, 1999). For those students who lack functional vision but do not have other significant disabilities, academic success is possible, particularly given the support of new technologies for assessment, accommodations and training (Helwig & Tindal, 2003; Quantum Simulations, 2005; Smith, Francioni, & Matzek, 2000). In fact, there have been recent calls for higher academic expectations for students with severe visual impairments (Ferrell, 2005).

There is also growing recognition that students who are blind are dramatically under-represented in the sciences at the college level and beyond (Kirchner & Smith, 2005; Rapp & Rapp, 1992). One reason is that these students face a disproportionate challenge in learning mathematics, for reasons that have not been clearly established (Blackorby et al., 2003; Fisher & Hartmann, 2005; Thahane et al., 2005). Unfortunately, low achievement in mathematics can be a barrier that impedes students without functional vision from full participation in science and engineering fields, and closes out students who are blind from a range of careers with salaries in the higher ranges (National Science Board, 2003; National Science Foundation, 2004).

Math word problem solving

The specific goal of the project is to learn more about math problem solving processes in blind students who are working at or near grade-level in school, and to employ innovative technologies to facilitate blind students' ability to solve word problems. We focus on math word problem solving because word problems are known to be challenging for many students, perhaps because these problems can place considerable demands on working memory (Swanson & Jerman, 2006). Prior research suggests that when students must devote cognitive resources to text comprehension, their math performance is negatively affected (Royer et al., 1999). For example, Helwig et al. (1999) found that poor readers performed better when math word problems were presented by video than text, indicating that reading difficulties can undermine math problem solving. Other studies indicate that efforts to understand English text detract from math problem solving by English Language Learners (Lara-Alecio, Cmajdalka, Parker, & Cuellar, 1996; Morales, 1998). By implication, the demands of comprehending word problem text might also contribute to the problem solving difficulties reported for blind students.

In addition, the contextual information afforded by rich word problems provides a window into the world of science, in which questions are grounded in authentic information, and which may engage students more readily than mathematical operations that are de-contextualized. It is also consistent with a general recommendation in mathematics education to connect mathematics with "real world" topics and to help students see the relation of math with other subjects (Lamon, 1999).

AnimalWatch: Online tutoring system for pre-algebra

Figure 1. Screen shot of division word problem from the Mongolian Takhi wild horse narrative.

The project strategy is to adapt AnimalWatch, an existing online math tutoring system currently in use in middle and high school classrooms in the Los Angeles area, for use by blind students. AnimalWatch provides practice and scaffolding in pre-algebra topics, including arithmetic operations, fractions, decimals, percentages, unit conversion, proportions, and one-variable equations. AnimalWatch includes a bank of approximately 1000 word problems about endangered species and associated environmental science issues. Each word problem includes an introduction with authentic background information, ranging from a few sentences to more complex text, followed by a problem question. Problem questions require the student to locate the relevant quantities in the introduction, construct the appropriate mathematics equation, perform the computation, and then enter the solution. An example is shown in Figure 1. The word problems have been indexed by species, mathematics topic (National Council of Teachers of Mathematics, and California Dept. of Education Mathematics Standards), and problem difficulty (ratings provided by teachers, and empirical difficulty based on performance by prior users). Each problem is illustrated with a unique image, table or other graphic. The word problems are organized into narratives or "virtual adventures" in which the student takes on the role of a field researcher charged with learning about the species and scientific efforts to monitor and sustain it: hence the system's name, "AnimalWatch" (Beal & Arroyo, 2002). The problem topics and content involve authentic information provided by partners such as the Zoological Society of San Diego, the National Zoo, and the New England Aquarium. As students solve word problems, their progress through the curriculum of math topics is individualized based on their problem solving performance, including accuracy of answers, latency, and requests to view scaffolding (Beck, Woolf & Beal, 2000; Brown et al., 1994).

Adaptations for VI students

Prior evaluations indicate that AnimalWatch is helpful, especially for low-achieving students (Arroyo et al., 2003; Beal, Adams & Cohen, 2008; Beal, Shaw & Birch, 2007). We are currently adapting AnimalWatch for use by blind students enrolled in the Los Angeles Unified School District's program for students with visual impairments. Blind middle school students will work with AnimalWatch during their math instruction period, using computers in the adjacent resource room. Computers are connected to the Internet, and are equipped with the JAWS screen reader software used to access navigation menu items, for example, the choice about which endangered species adventure to work on.

Additional adaptations are required to present the AnimalWatch word problems to blind students. One option would be to translate the word problems into Braille, but this is prohibitive in terms of time and resources, especially as each student typically views a unique sequence of word problems that is generated and adjusted in real time by the software. A greater challenge is many of the students in our target population are adventitiously blind and are not proficient in Braille. Thus, the project strategy is to present the word problems as audio clips. A screen shot of the prototype may be viewed in Figure 2.

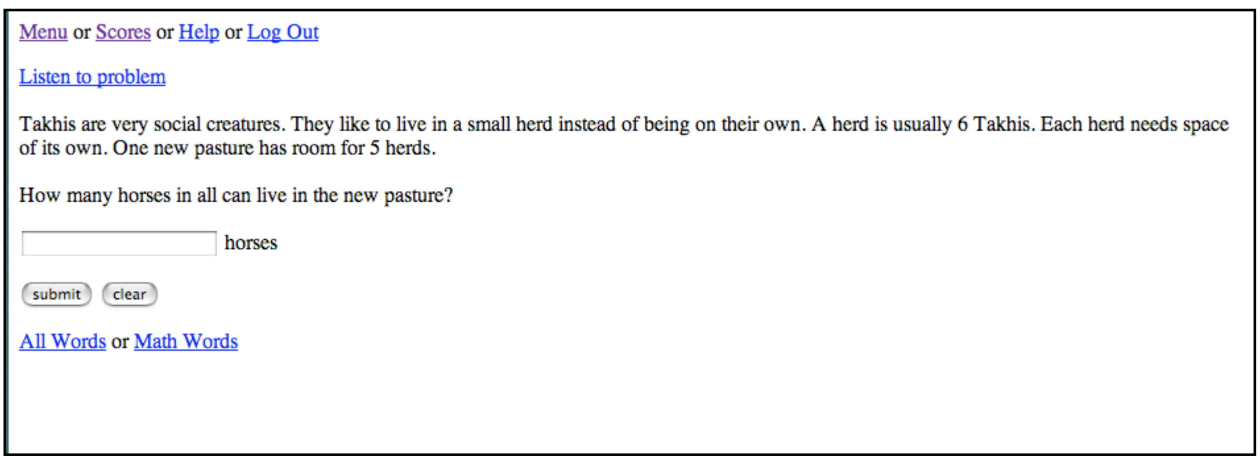

Figure 2. Screen shot of prototype interface for audio word problem presentation

Due to the large number of word problems in AnimalWatch, the process of creating audio versions of the word problems is being automated by using text-to-speech technology (Cepstral software). The technology provides mark-up tools to customize the intonation and expressivity of the synthetic voice, and to fine-tune pronunciation of technical terms. Pilot work is being conducted to establish if the results of the text-to-speech conversion are acceptable to the students who are our target users.

Another planned adaptation involves integrating additional details about the endangered species that are the focus of the word problems, to address the need to motivate blind students as they solve a series of challenging word problems. The images in the original version are usually not essential for solving the problems, but serve to sustain motivation: Students like the pictures, and the images provide them with important background and contextual information about the environmental science topics. To address this issue, the episodes will be organized so that blind students will receive engaging factual information and audio information (e.g., an audio clip of the snow leopard's unusual hoarse vocalizations) about the animals after completing a target number of problems (typically, 5-8 word problems).

Measures of word problem solving by blind students

Blind students will be able to replay the audio-format word problems as needed. Problem replays will be tracked as one indication of students' ability to process the problem information as a function of text characteristics such as the number of words, and the grade-level readability of the text. We hope to identify the characteristics of rich word problems that blind students can comprehend readily without sapping working memory capacity needed to perform math operations. We will also track other measures of blind students' math problem solving, including their solutions (answers, accuracy and, in the case of errors, status as a near-neighbor of the correct response), the time required for each attempt, and access to scaffolding, for each problem. These data are automatically recorded by the software and can be extracted for analysis off-line, including comparisons with problem solving data from sighted students.

We are particularly interested in blind students' strategies on word problems where the initial answer is not correct. AnimalWatch currently provides immediate answer feedback in the form of text messages (e.g., "Yes, you've got it!" "No, that's not quite right".) That is, the first level of text messages serve the function of telling the student that the answer was or was not correct. The second level provides some very limited scaffolding in terms of the operation required for the solution, e.g., "Are you sure you're using subtracting?"). The third level involves a suggestion that the student view multimedia help resources, including interactive worked examples and video lessons. If the student enters an incorrect answer on the fourth attempt, the correct answer is provided. Our previous work with sighted students indicates that they correct about half of their problem solving errors after the initial two text messages about accuracy and required operation (Arroyo et al., 2003). That is, students often do not require more extended help to figure out what they did wrong, and it may not be pedagogically useful to require the student to review a detailed explanation of the answer in these cases. One empirical question is whether students who are blind will also self-correct when informed that the answer is not right, and if their ability to self-correct will be facilitated by selection of word problems that do not overwhelm working memory capacity. This is especially critical because completely adapting the multimedia resources (such as the interactive worked examples and the video lessons) for blind students is not feasible in the current project.

Future work: Selecting word problems for VI students

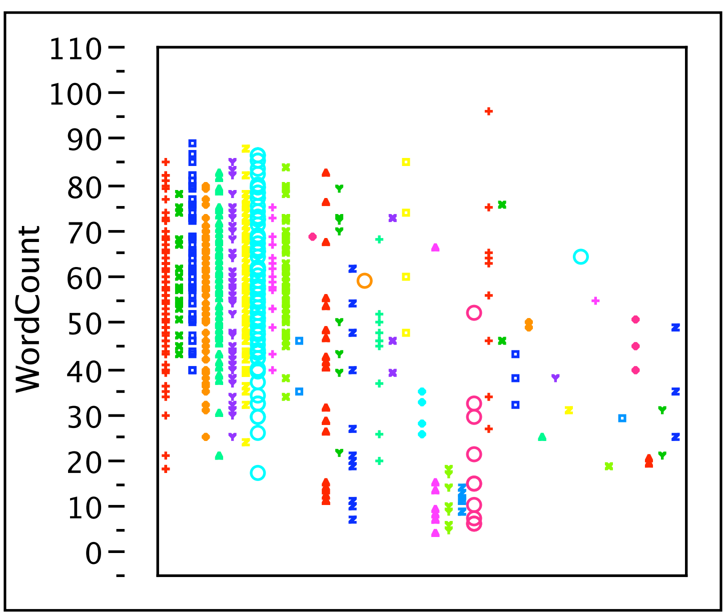

Figure 3. Word problems in AnimalWatch by word count and math topic

An individual student typically sees only a small percentage of the available word problems in AnimalWatch. The specific problems shown to a particular student are determined by the problem selector mechanism, which maintains estimates of the student's proficiency in the target math skills. Figure 3 shows the distribution of word problems by the number of words in the problem text for over 30 different math topics (X axis). For a specific math topic, e.g., simple addition (left-most column in Figure 3) there are likely to be many word problems that will not be suitable for blind students because the working memory demands of comprehending the audio version are simply too great. We will use data (replay actions, accurate and inaccurate solutions, etc.) from an initial cohort of blind students to define the characteristics of word problems that are likely to be appropriate for audio presentation. The AnimalWatch problem selector will then be trained to sweep through the space of available candidates in the word problem database, and choose from those that best fit the criteria for students without vision (Beck et al., 2000). In the future, this feature may also be useful for students with reading disabilities.

References

Arroyo, I., Murray, T., Beck, J., Woolf, B. P., & Beal, C. R. (2003, July). A formative evaluation of AnimalWatch. Proceedings of the 11th International Conference on Artificial Intelligence in Education, IOS Press.

Beal, C. R., Adams, N. M., & Cohen, P. R. (2008). Reading proficiency and mathematics problem solving by high school English Language Learners. University of Southern California. Manuscript under review. Available by request from cbeal@isi.edu.

Beal, C. R., & Arroyo, I. (2002). The AnimalWatch project: Creating an intelligent computer math tutor. In S. Calvert, A. Jordan, & R. Cocking (Eds.), Children in the digital age, pp. 183-198. Westport CT: Greenwood.

Beal, C. R., Shaw, E., & Birch, M. (2007). Intelligent tutoring and human tutoring in small groups: An empirical comparison. In R. Luckin, K. R. Koedinger, & J. Greer (Eds.), Artificial intelligence in education: Building technology rich learning contexts that work (pp. 536-538). Amsterdam: IOS Press.

Beck, J. E., Woolf, B. P., & Beal, C. R. (2000). Learning to teach: A machine learning architecture for intelligent tutor construction. Proceedings of the Seventeenth National Conference on Artificial Intelligence, Austin TX.

Blackorby, J., Chorost, M., Garza, N., & Guzman, A. (2003, updated 2005). The academic and middle school performance of students with disabilities. Special Education Elementary Longitudinal Study (SEELS) Report. Menlo Park CA: SRI International.

Brown, A. L., Ellery, S., & Campione, J. (1994). Creating Zones of Proximal Development electronically. In J. Greeno & S. Goldman (Eds.), Thinking practices: A symposium in mathematics and science education. Hillsdale NJ: Erlbaum.

Chen, X. (2005, Jan.). Mixed-mode dialogue information access for the visually impaired. Accessibility and Computing, 81, 16-19.

Fisher, S. P., & Hartmann, C. (2005). Math through the mind's eye. Mathematics Teacher, 99, 246.

Ferrell, K. A. (2005). The effects of NCLB. Journal of Visual Impairment and Blindness, 99, 681-683.

Helwig, R., Rozek-Tedesco, M. A., Tindal, G., Heath, B., & Almond, P. J. (1999). Reading as an access to mathematics problem solving on multiple-choice tests for sixth-grade students. Journal of Educational Research, 93, 113-125.

Helwig, R., & Tindal, G. (2003). An experimental analysis of accommodations decisions in large-scale mathematics tests. Exceptional Children, 60.

Kirchner, C., & Smith, B. (2005). Transition to what? Education and employment outcomes for visually impaired youth after high school. Journal of Visual Impairment and Blindness, 99, 499-504.

Lamon, S. (1999). Teaching fractions and ratios for understanding. Mahwah NJ: Erlbaum.

Lara-Alecio, R., Cmajdalka, S. J., Parker, R. I., & Cuellar, R. Y. (1996, April). A three year study of a new pedagogical theory-model in a bilingual education program using mathematics as a vehicle of instruction. Paper presented at the annual meeting of the American Educational Research Association, New York NY.

Morales, R. V. (1998, Feb.). Comprehension and solution patterns of simple math word problems by Mexican-American, bilingual elementary school students. Paper presented at the annual meeting of the National Association for Bilingual Education, Dallas TX.

National Science Board. (2003). The science and engineering workforce: Realizing America's potential. National Science Foundation: Arlington VA.

National Science Foundation. (2004, May). Women, minorities and persons with disabilities in science and engineering. Arlington VA. Updated March 2006.

Quantum Simulations. (2005, Oct.). World's first artificial intelligence tutoring software for blind and visually impaired students. Retrieved Jan. 23, 2007 < http://www.quantumsimulations.com/news21.html >

Rapp, D. W., & Rapp, A. J. (1992). A survey of the current status of visually impaired students in secondary mathematics. Journal of Visual Impairment and Blindness, 86, 115-117.

Royer, J. M., Tronsky, L. N., Chan, Y., Jackson, S. J., & Merchant, H. (1999). Math fact retrieval as the cognitive mechanism underlying gender differences in math test performance. Contemporary Educational Psychology, 24, 181-226.

Smith, A. C., Francioni, J. M., & Matzek, S. D. (2000). A Java programming tool for students with visual disabilities. Proceedings of the Fourth International ACM Conference on Assistive Technologies, 142-148.

Swanson, H. L., & Jerman, O. (2006). Math disabilities: A selective meta-analysis of the literature. Review of Educational Research, 76, 249-274.

Steinkuller, P. G., Du, L., Gilbert, C., Foster, A., Collins, M. L., & Coats, D. K. (1999). Childhood blindness. Journal of the American Association of Pediatric Opthamology and Strabismus, 3, 260-32.

Thahane, L. N., Myburgh, C. P. H., & Poggenpoel, M. (2005). The life-world of visually-impaired adolescents: An educational guidance perspective. Education, 125, 393.

Walker, B. N., Lindsay, J., & Godfrey, J. (2004, Oct.). The Audio Abacus: Representing numerical values with nonspeech sound for the visually impaired. ASSETS '04, 9-15.

Yesilada, Y., Stevens, R., Goble, C., & Hussein, S. (2004, Oct.). Rendering tables in audio: The interaction of structure and reading styles. ASSETS '04, 16-23.

Acknowledgements

The project is supported by a grant from the National Science Foundation program (RDE 0725917). We would like to thank Shirley Ann Kirk, Lore Schneider and Joe Amato from the Los Angeles Unified School District's Program for the Visually Impaired for their assistance with the project. We would also like to thank K12@USC Project colleagues Joshua Moody, Jean-Philippe Steinmetz, Teresa Day and Mike Birch.