Evaluation of the Effectiveness of a Tablet Computer Application (App) in Helping Students with Visual Impairments Solve Mathematics Problems

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Structured abstract: *Introduction:* The authors examined a tablet computer application (iPad app) for its effectiveness in helping students studying pre-algebra to solve mathematical word problems. *Methods:* Forty-three visually impaired students (that is, those who are blind or have low vision) completed eight alternating mathematics units presented using their traditional literacy medium or an iPad app. Twenty percent of the mathematics problems included graphics such as maps, line graphs, and bar graphs. During each session, teachers of visually impaired students rated the amount of support they provided for students and the student motivation. *Results:* Students answered more mathematics problems correctly when using the iPad app and, overall, teachers reported that their students were more motivated with the app than with their traditional literacy medium. Students often used the hints provided in the app when they did not solve a problem correctly the first time. *Discussion:* Visually impaired students and their teachers found the app and graphics to be easy to use and motivating. The built-in Scratch pad was used by almost all students who were print users. *Implications for practitioners:* The study results contribute to the growing body of knowledge about the potential value of tablet-type devices for use by visually impaired students.

Academic outcomes and employment prospects for visually impaired students (that is, those who are blind or have low vision) are generally lower than are those of sighted peers (McDonnall, 2011; Wagner, Newman, Cameto, & Levine, 2006). The achievement gap is especially apparent in mathematics (McDonnall, Geison,

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& Cavenaugh, 2009; National Science Foundation [NSF], 2009). These visually impaired students show substantially lower achievement in mathematics than do their sighted peers, as well as reduced participation in mathematics-intensive science and engineering fields (NSF, 2009; Wolffe, Sacks, Corn, Erin, Huebner, & Lewis, 2002). Vision provides important access to information that supports the development of conceptual understanding in mathematics. "Descriptions of mathematical concepts that appeal to visualization may enjoy immediacy for the sighted student, but they require significantly more cognitive processing for the visually impaired" (Dick & Kubiak, 1997, p. 344). For example, understanding how a shape rotates across an axis is difficult to comprehend with no or limited vision.

Access to visual information presented in the education classroom enables a visually impaired student to focus on acquiring academic knowledge, rather than on struggling with access issues (Lewis & Allman, 2014). These students need more support to complete tasks and may appear less engaged in the classroom, perhaps because they are given relatively few opportunities to direct their own learning (Agran, Hong, & Blackenship, 2007; Bardin & Lewis, 2008; Robinson & Lieberman, 2004; Sacks, Wolffe, & Tierney, 1998; Wagner et al., 2006). Educators and researchers have pointed to the need to promote independence and self-determination for these students (Algozzine, Browder, Karvonen, Test, & Wood, 2001; Hatlen, 1996; Sacks & Silberman, 1998; Wolffe, Rosenblum, & Cleveland, 2014). Within mathematics and science classes, supporting these students in determining when they need to use alternative materials and strategies to complete a task or to work with a peer are ways to give them the opportunity to find ways that are effective for them to participate and access information.

Assistive technologies offer the potential to provide accessible instruction to visually impaired students, and to do so in a way that will promote their independence (Freeland, Emerson, Curtis, & Fogarty, 2010; Kapperman, Sticken, & Heinze, 2002; Kelly, 2009; Kelly & Smith, 2011; Zhou, Smith, Parker, & Griffin-Shirley, 2011) as well as their motivation (Campana & Ouimet, 2015; Shah, 2011; Williams, 2012). In the area of mathematics education, several pilot projects have shown promising initial findings, including the Talking Tactile Tablet, which provided visually impaired students with access to graphical information supplemented by audio narration (Hansen, Shute, & Landau, 2010; Landau, Russell, Gourgey, Erin, & Cowan, 2003). Other early technology projects are described by Ferrell (2006).

The goal of the present project was to develop assistive technology to promote mathematics proficiency in visually impaired students with a specific focus on solving word problems. Solving word problems is generally considered to be an important component of mathematics proficiency, particularly given the additional emphasis on applications in the Common Core State Standards for Mathematics (Powell, Fuchs, & Fuchs, 2013). A key objective in the technology design was to ensure that the student would have the opportunity to work independently as much as possible. We designed a tablet computer application (iPad app) to assist these students in solving word problems in mathematics, and we followed an iterative development process that involved feedback from these students and their teachers to ensure usability (Beal & Rosenblum, 2015).

Description of the iPad app

A detailed description of the iPad app and accompanying materials is available in Beal and Rosenblum (2015). It contained 24 mathematics units, each featuring an endangered species (such as a snow leopard or a polar bear). Each unit started with four introductory pages containing information about the featured species and the mathematics topic the unit covered. The unit introduction was followed by six word problems presented in a fixed order. Four of the problems included an illustrative image, and two involved a mathematics graphic (for example, a line graph or a map). Students were allowed three attempts to answer each problem. If a wrong answer was entered, hint 1 became available, followed by hint 2 if the student entered a second wrong answer. The first hint guided the student to select the type of computation needed, and the second hint guided the student in setting up the problem for computation. Students had to actively open the hint to view the text or to listen to the audio. After three incorrect answers, they could access a brief narrated video that outlined the solution; the solution was also available after a correct answer was entered. Students always had the option to give up on (skip) a problem and view the solution; if a student chose this option, the answer was considered to be incorrect. A short text conclusion with an image was presented at the end of each unit.

The mathematics units covered a range of algebra-readiness topics such as arithmetic, fractions, rates, one-variable expressions, geometry (angles), and statistics (averages). Course content was aligned to the Common Core State Standards for Mathematics for grade 6. Units were grouped into difficulty levels roughly corresponding to grade 5–6 (level 1), grade 6 (level 2), and grade 6–7 (level 3) mathematics topics. When a student who was a braille user was completing an app unit, the student had two options for accessing the information. The first was to access the content in the app either using VoiceOver, the screen reader that is available in Apple devices, or a refreshable braille display. When computing the answer to the two word problems that had information in graphics, they had to refer to the braille booklet that was provided. The second option was to use the braille booklet that included all the text on the screens, including the hints and the two graphics needed to solve two of the six mathematics problems. When using the braille booklet during an app unit, they were instructed to not read a hint until after an answer was entered. When using the app, students with low vision were provided large print paper copies of the two graphics needed to solve two of the six mathematics problems, but they were not provided the text of what appeared on the screen. For sessions in which students did not have access to the app, paper units were used in the student's primary literacy medium. Both in braille and large print, these included the same introduction pages and problem text information. The two graphics that were required to solve two of the six word problems were included in the paper units, but the hints were not. Through the study we sought answers to three questions.

1. Is there a difference in students' problem solving when using the app compared to using only the paper materials prepared in their primary literacy medium? (The data source was the number of mathematics problems correctly solved in the two conditions.)
2. Do students have a preference for material to be presented via an app or only via paper in their primary literacy medium? (Data sources included teachers' impressions of students' motivation in the two conditions, and teacher and student comments during post-study interviews.)
3. Are students able to work more independently when completing mathematics units using the app compared to units presented only via paper in their primary literacy medium? (Data sources included students' use of hints in the app condition, and teacher and student comments during post-study interviews.)

Methods

Recruitment

Information about the study was posted on electronic mailing lists, shared at conferences, and posted on the project website. Students who qualified for the study were receiving direct educational services as a visually impaired student from a teacher, studying algebra-readiness mathematics, and using an iPad. Interested teachers were provided with a consent packet to share with the student's family and a consent packet for themselves. Both the student and the teacher had to complete the consent process in order to participate. Students provided assent at the start of the protocol. The project was reviewed and approved by the university's institutional review board.

Participants

Forty-three students—21 females (49%) and 22 (51%) males—from 17 U.S. states participated. Sixteen (37%) were braille users and 27 (63%) used print. Eight (19%) students had retinopathy of prematurity; seven (16%) had albinism; four each had cataracts (9%), Leber's congenital amaurosis (9%), and optic nerve hypoplasia (9%); three (7%) had glaucoma; two (5%) had rod-cone dystrophy; and 11 (26%) had other or mixed conditions. Fifteen (35%) students attended specialized or residential schools and 28 (65%) attended public schools. Students were in fourth (n = 1, 2%), fifth (n = 11, 26%), sixth (n = 8, 19%), seventh (n = 13, 30%), eighth (n = 6, 14%), ninth (n = 3, 7%), and tenth (n = 1, 2%) grades.

Thirty teachers participated: 21 (70%) had one student in the study, six (20%) had two students, two (7%) had three students, and one (3%) had four students.

Procedure

Teachers of visually impaired students

Individually, teachers completed a 1.5- to 2-hour online training protocol comprised four modules that provided background about the project, features of the app, accessibility features of the iOS environment, and study procedures. Next, a package of study materials was sent to the teacher of visually impaired students that included: (a) a user guide; (b) directions for downloading and installing the app and establishing the student's account;

(c) a reminder sign of study procedures to post where the student was completing study activities; (d) four mathematics paper units (these had only the introductory pages, problems, and two graphics in the student's primary learning medium); (e) for braille readers, four mathematics units that corresponded to those presented in the app (these had all content in the app including the introduction pages, problems, graphics, hints, and glossary terms); (f) for large print users, a booklet of graphics shown in the four units presented in the app; and (g) for the teachers, data-recording forms to be used during each of the sessions. These data-recording forms were also available via an iPhone app the teacher could install if desired. The data forms asked the teacher to specify the materials used by the student (for instance, a braillewriter or an abacus) and assistance that was provided during each session. The study instructions included an explanation of the order in which units were to be completed by the student, and this same order was presented in the app when the student logged in to his or her account. A "P" was shown next to the names of units to be completed using the paper format.

Visually impaired students

Students were assigned to complete eight units in one of the three mathematics levels based on recommendations from their teacher (with consultation from the student's general education mathematics teacher in choosing the mathematics level). A sample problem for each unit was provided to guide the teachers in determining which of the three levels was appropriate for the student. Six braille users and 11 print users completed units in level 1; three braille users and 11 print users completed level 2 units; and seven braille users and five print users worked on level 3 units. Students were assigned to complete four units while using the app, and four paper units. App and paper units were alternated across sessions for each student. Half of the students started with an app unit, and the others started with a paper unit. Presenting both paper and app units provided a way to determine if the supports provided by the app increased students' problem-solving performance, and whether it allowed both the student and the teacher to compare presentation of the material in a traditional format to a technological format.

In the first session, all students completed a training unit designed to introduce them to the app, including basic navigation, the option to adjust settings (for instance, font color and contrast, and audio speed), how to access the glossary (definitions of key terms appearing on the page), image descriptions, mathematics problem hints, the Scratch pad (a workspace for computation), and how to use the Enter Answer pad (keys designed to allow students to enter answers that included numbers, a slash to denote a fraction line, and a key to bring up the Scratch pad). The training unit included three practice problems. The unit was not one of the eight units used for data collection.

After completing the training unit, students typically worked on the assigned eight units over a period of several weeks to several months under the direction of the teacher. The teacher mailed units completed via paper to the research team. Data from the app units (for instance, answers entered or number of attempts per problem) were automatically transmitted to the project server when the iPad detected an Internet connection.

During each session, the teacher used the data recording form (either on paper or via iPhone) to record the amount of assistance provided on each problem. Ratings were on a 5-point Likert-type scale: 0 = no help, 1 = a little help, 2 = some help, 3 = moderate help, and 4 = a lot of help. It was at the teacher's discretion to assign the rating. During the online training session, a sample video was provided of a teacher using the iPhone app to rate a student's work on a problem. Separate ratings were entered for help with the app for the four units (for example, adjusting settings, page navigation, or using the Enter Answer pad), help with understanding the problem (for example, identifying the correct mathematics operation), help with mathematics computation, and help with understanding the mathematics graphics (only for the two word problems involving mathematics graphics per unit). At the end of each unit teachers were provided with the statement, "I thought the student's level of motivation to solve the problems was:" and were asked to assign a rating of 1 = very low, 2 = low, 3 = average, 4 = high, or 5 = very high. Ratings that were entered on an iPhone were automatically transmitted to the project server. Paper data recording forms were mailed to the research team.

When the mathematics units were completed, the second author scheduled individual telephone interviews with the students and their teachers. Forty (93%) of the students and 27 (87%) of their teachers were interviewed. Students were asked if they had a preference for the app or paper units, to explain their preference, and to provide feedback about the app features. Teachers were asked to comment on any differences they observed in the student's problem solving with the app versus paper units, and to suggest additional features or ways the app could be improved.

Results

A least-squares MANOVA with mathematics level (1, 2, 3) and literacy medium (braille, print) as between-subjects factors and unit type (app or paper) as a within-subject factor was conducted with the dependent measure changing based on what was analyzed (such as the number of problems solved correctly or the number of problems for which the teacher provided no help).

Students' mathematics problem-solving

Comparison of app and paper units

The total number of problems solved correctly was summed for each student for app units (24 possible) and paper units (24 possible). Mean scores are shown in Table 1.

The only significant effect was for unit type, $F(1, 37) = 53.805$, $d = 1.03$, $p < 0.001$. Students solved more problems correctly when working with the app ($M = 21.4$) than when problems were presented on paper ($M = 16.7$). In absolute terms, 38 (88%) of the students did better with the app units, 3 (7%) performed the same on the app and paper units, and 2 (5%) did better with paper units.

When students worked on app units, the number of attempts made on a problem was automatically recorded (three tries possible for each problem). Mean problem-solving performance by attempt is shown in

Table 1
Mean number of word problems correctly solved by mathematics level for braille and print users.

Literacy medium	Level 1 App	Level 1 Paper	Level 2 App	Level 2 Paper	Level 3 App	Level 3 Paper
Braille	22.33 (1.86)	16.5 (3.73)	23.33 (1.54)	17.00 (5.19)	20.14 (3.43)	14.28 (4.42)
Print	22.18 (3.33)	17.90 (5.92)	20.63 (2.57)	17.72 (5.06)	20.60 (2.57)	15.20 (4.32)
All users	22.23 (2.86)	17.42 (5.17)	21.21 (2.57)	17.57 (4.89)	20.33 (2.70)	14.66 (4.20)

Standard deviations are shown in parentheses. There were 24 app problems and 24 paper problems.

Table 2. Comparable information about attempts was not available for paper units. The number of app problems solved correctly on the first attempt was compared to correct solutions for paper units. Students solved 14.2 (59%) of app problems correctly on the first try, compared to 16.7 (69%) of paper unit problems correctly solved, $F(1,37) = 7.016$, $p < .01$.

When students did not answer an app problem correctly on the first attempt, hints became available. Braille users activated an average of 1.02 hints per problem not correctly answered on the first try. Hint use by braille users on app units may actually have been higher because the hints were reproduced in the braille copies provided with the app units, but we had no way to record if a student used the hints provided in braille (instead of activating them in the app). Print users activated an average of 1.29 hints per problem not correctly answered on the first try. The number of app problems not correctly answered on the first try was a significant predictor of total hints activated, $F(1,41) = 60.031$, $d = 0.59$, $p < 0.001$.

Use of app features

The glossary feature was rarely used: 13 (81%) braille users and 24 (89%) print users never used it. Use of the narrated solution videos was also low: eight (50%) braille users never accessed a video, three (19%) accessed a single video, one (6%) accessed two videos, two (13%) accessed three videos, and two (13%) accessed five videos of the 24 available in the app units. Seventeen print users (63%) never accessed a video, 3 (11%) accessed a single video, 2 (8%) accessed 2 videos, and 5 (19%) accessed 3 videos of the 24 available in the app units. The Scratch pad was used by 27 (100%) of the print users. Not surprisingly, Scratch pad use by braille users was low: 12 (75%) never opened it, and 4 (25%) opened it once or twice but did not actively use it for computation.

Table 2
Mean number of app problems by outcome.

Literacy medium	Correct 1st attempt	Correct 2nd attempt	Correct 3rd attempt	Strikeout (incorrect)	Give up (incorrect)
Braille	14.35 (5.21)	4.5 (2.22)	2.62 (2.09)	2.06 (2.64)	0.50 (1.09)
Print	14.04 (4.00)	5.0 (1.90)	2.29 (1.81)	2.03 (2.04)	0.63 (1.41)
All users	14.16 (4.43)	4.81 (2.01)	2.41 (1.90)	2.04 (2.25)	0.58 (1.29)

Standard deviations are shown in parentheses. There were 24 app problems.

Table 3
Means and standard deviations for the amount of help provided to students by their teachers.

Literacy medium	No help	A little help	Some help	Moderate help	A lot of help
Help with navigation					
Braille	20.4 (5.42)	2.0 (2.75)	0.73 (1.33)	0.33 (1.03)	0.53 (1.06)
Print	22.0 (2.68)	1.85 (2.72)	0.09 (0.30)	0.0 (0.0)	0.05 (0.21)
Help with understanding the problem					
Braille					
App units	14.8 (4.72)	4.67 (3.15)	2.20 (2.36)	0.67 (0.97)	0.86 (1.68)
Paper units	17.46 (4.44)	2.13 (2.16)	1.33 (1.87)	1.33 (1.47)	0.8 (1.32)
Print					
App units	18.38 (6.15)	3.0 (4.14)	1.33 (2.0)	0.33 (0.85)	0.38 (0.66)
Paper units	19.00 (6.26)	3.43 (4.51)	0.66 (1.11)	0.47 (0.81)	0.14 (0.35)
Help with math computation					
Braille					
App units	15.26 (5.89)	3.0 (2.56)	2.33 (2.76)	1.13 (1.30)	1.46 (1.88)
Paper units	16.66 (7.16)	2.6 (2.55)	1.53 (1.80)	0.66 (1.17)	1.73 (2.12)
Print					
App units	18.23 (6.15)	2.47 (2.90)	1.14 (1.98)	1.0 (1.54)	0.47 (1.77)
Paper units	18.04 (7.57)	2.95 (3.26)	1.85 (3.27)	0.47 (1.07)	0.4 (0.82)
Help with graphics					
Braille					
App units	4.46 (3.41)	1.9 (1.67)	0.27 (0.45)	0.40 (0.91)	0.53 (0.83)
Paper units	5.26 (2.37)	0.73 (0.96)	0.73 (0.96)	0.53 (0.83)	0.33 (0.72)
Print					
App units	7.00 (1.70)	0.62 (1.24)	0.95 (0.43)	0.09 (0.30)	0.00 (0)
Paper units	6.50 (2.52)	1.19 (1.99)	0.43 (1.03)	0.09 (0.30)	0.00 (0)

Standard deviations are shown in parentheses. There were 24 app problems. There were eight app problems and eight paper problems that included a math graphic. Ratings ranged from 0 for "no help" to 4 for "a lot of help."

Help provided by the teacher

Teachers recorded assistance they provided to students with navigation of the app, interpretation of problems, computation of mathematics, and understanding the graphics. For each, scores ranged from 0 (none) to 4 (a lot of help).

Navigation of the app

Ratings reported in Table 3 were provided for 41 students (15 braille users and 26 print users). Data reported is for the mean and standard deviation of the amount of help provided the student by the teacher. Students did not need much assistance with using the app; on average, they completed 21 (87%) of 24 app problems without any help from the teacher with navigation issues such as hint access, answer entry, or moving through problems.

Interpretation of problems

Results for app and paper units are shown in Table 3. Data reported is for the mean and standard deviation of the amount of help provided to the student by the teacher. Results of the MANOVA for the number of problems on which teachers provided no help with interpretation of problems showed that the effect of unit type was significant, $F(1,34) = 6.221$, $d = -0.43$, $p < 0.05$. Teachers were less likely to provide help on paper problems ($M = 18.36$) than on app problems ($M = 16.88$). Braille users needed some form of help on about 8 (33%) of 24 app unit problems, and on about 5.5 (23%) of 24 paper unit problems. Print users needed help on about 5 (21%) of 24 app unit problems and 4.7 (19%) of paper unit problems.

Computation of mathematics

Results for app and paper units are shown in Table 3. Data reported is for the mean and standard deviation of the amount of help provided to the student by the teacher. Results of the MANOVA for the number of problems for which teachers provided no help with mathematics computation found no significant effects. Braille users needed some form of help with computation on about eight (33%) of 24 app unit problems, and on about 5.5 (23%) of 24 paper unit problems. Print users needed help with computation on about five (21%) of 24 app unit problems and 5.7 (24%) of paper unit problems.

Understanding the graphics

Mean scores for help given to students in understanding the graphics are shown in Table 3. Data reported is for the mean and standard deviation of the amount of help provided to the student by the teacher. The interaction of literacy medium and unit type was significant, $F(1,33) = 4.342$, $p < 0.05$. Braille users needed some form of help with mathematics graphics on about 2.5 (31%) of the eight app problems that involved graphics, and about three (37.5%) of the eight paper unit problems that involved graphics. Print users needed some form of help with mathematics graphics on one (12.5%) of the eight app problems that involved graphics, and about 1.5 (18.75%) of the eight paper unit problems that involved graphics.

Motivation of students

Teachers provided an overall rating of the apparent motivation of students during each session, with scores ranging from 1 (very low) to 5 (very high). Results of the MANOVA for motivation showed there was a significant effect of unit type, $F(1,39) = 32.667$, $d = 0.55$, $p < 0.001$. Students appeared to be more motivated when working on app units ($M = 4.29$, $SD = 0.69$) than on units presented in paper ($M = 3.88$, $SD = 0.88$).

Interviews

Students

When asked about their preferences, 31 (78%) of the students said they preferred working with the app, and two students (5%) said they liked both the app and their primary literacy medium. Six students (15%, three braille users and three print users) said they preferred working with their primary literacy medium, and one student (2%) said he was not sure.

Of those who preferred the app, 16 (52%) referred to the hints and five (16%) mentioned the audio feedback as the reason for preferring the app over paper. Of the 16 (52%) students who said they liked the app because of the hints, six (19%) also mentioned the audio feedback signaling whether the answer was correct or wrong. One print user commented, "I liked knowing if I got the answer right in the app. . . . On paper, my teacher had to help me once in a while. When I used the app, she didn't help me as much. With the app, I didn't really have to ask her to help me."

Three (10%) students said they liked the app because they had the option to listen instead of read, three (10%) said the iPad was easier to use than paper, two (6%) mentioned the Scratch pad, and two (6%) did not give a reason. The six students who preferred their primary literacy medium mentioned that it was easier to work with familiar materials than with the less familiar iPad. Interestingly, four of these students, all of whom were print users, did not realize that the iPad app included an audio option.

Sixteen (40%) students commented that they liked the content of environmental science word problems in both paper and app units: "It was more interesting than my regular math," said one student. Another commented, "I liked that science and math were together." Eight (20%) students specifically mentioned that they liked the audio of the animal sounds included in the app: "It was interesting because of the sounds and the pictures. I would love to keep going!" commented a student.

Teachers

Twenty-one (78%) of the teachers said during the interview that their students seemed more engaged with the app, and six (22%) reported that they did not see a difference. No one said that their student was more engaged when working with paper units. Eight (30%) teachers mentioned that their student worked more independently with the app. One teacher commented about a print user, "She made more mistakes on paper and needed more help from me. When she could do things in the app her speed improved and her confidence. If she had something like this in math class, she would do better." Another commented, "I really liked the hints and how it encouraged (my students) to try to figure it out on their own." One explained for a braille reader, "With him being a slow reader, the paper was hard. He'd ask me to read it to him. With the app, he was independent and successful." Another noted of a print user:

> She liked the hints and got to figure out the problem on her own which made her think. With paper and pencil, she usually looks for someone to give her the answer and doesn't try to think it out. She really did work through the [app] problems trying to get the concepts which helped her self-esteem. Her mom and I spoke and she is participating more in math class [since the study].

Discussion

The goal of the study presented here was to compare the solving of mathematics word problems by visually impaired students when presented in their primary literacy medium or through an iPad app with accompanying graphics. The app had been developed specifically to meet the needs of visually impaired students and had undergone extensive prior usability testing (Beal & Rosenblum, 2015).

With regard to problem solving, students correctly solved more problems presented in the app than in those presented in their primary literacy medium. Better performance with the app was observed for both print and braille users, and for different mathematics levels. The app provided immediate feedback about whether an answer was correct or not, as well as hints to guide problem solving. These features appeared to encourage students to persist when working with the app. When they did not get the problem correct on the first attempt, they tried again and ultimately solved 90% of the problems. They rarely gave up on a problem, even though the option to do so was readily available. Most of the students said they preferred working with the app, mentioning the feedback and hints as the reason.

When interviewed, 30% of the teachers commented that their students worked more independently with the app. One said, "It was like having a teacher right there." Of course, one key difference between the app and a teacher is that the app provided resources, but it was up to the student to decide whether to use them. For example, use of the hints was related to the number of problems correctly solved in the app, but students did not always choose to use the hints. Students rarely used resources that were not directly related to problem solving such as the glossary or narrated videos explaining how to solve a problem when they had already completed it, even if they had not gotten it correct.

Interestingly, although teachers reported in interviews that students were more independent with the app, their ratings for the amount and type of help provided per problem tell a slightly different story. Teachers were actually more likely to help students with interpreting the mathematics problem in app units than in paper units, and they gave braille users more assistance with locating information in mathematics graphics in the app units. Since braille readers used paper graphics for both app and paper units, this may simply be due to the fact that students could try up to three times on an app problem, which may have provided more opportunity for the teacher to clarify a student's misunderstanding. It should be noted that when teachers did provide assistance on a problem, in most cases they described it as "a little bit of help."

When using the app, according to the teachers, students appeared more motivated than when doing paper units. This impression is supported by the finding that most students reported preferring to work with the app. It is possible that students' higher motivation was due to a novelty effect of working with technology. However, the study involved eight alternating sessions (four with paper and four with the app) over a period of several weeks to months, which would seem to be sufficient experience for any transient benefits associated with novelty to fade. Also, although a number of students described the app as "fun," it did require them to solve sometimes-challenging mathematics word problems, and the higher level of motivation when using the app was associated with observable effortful behaviors such as persisting in problem solving and using hints.

Overall, the results of the evaluation appeared to be generally supportive of the use of assistive technology in the form of an iPad app to support students' mathematics problem solving. Students performed better, seemed to be less dependent on their teacher, and appeared to be more motivated than when they worked with print or braille. However, the study results also raised an issue that was not anticipated but that deserves additional attention, in particular, with regard to the role of audio as a means to access information. The option to access the problem text and image descriptions via audio was appealing, particularly to students who were not efficient braille readers. In fact, it is possible that for some users, a preference for the app might have reflected a desire to avoid using braille. One braille reader commented, “I had less to read with the app,” and another said, “I liked units with the app better . . . [because] you don’t have to read braille.” Another mentioned that it was easier to use the iPad than the braille book.

Audio was also an appealing option for several print users. One print user mentioned that she liked having the app read to her because “it gave my eyes a break,” and another mentioned she went to the audio “when my eyes were tired.” Interestingly, four of the six students who preferred working with paper did not know that the app provided an audio option (because their teacher did not introduce it to them). Certainly, not all visually impaired students like audio as a means to access information. However, given the importance for these students to have an efficient literacy medium that enables them to be competitive, it is important to consider carefully how the option to access audio might impact their proficiency with print or braille. This issue is likely to become increasingly pressing given that the ready availability of text-to-speech software means that it is now fairly straightforward, quick, and inexpensive to create audio representations of text that is of reasonable quality.

Limitations

The study had a number of limitations. First, teachers were asked to select a mathematics level for a student, yet no verification of a student’s actual mathematics skills or content being learned in mathematics class was provided. Therefore, some students may have already mastered the content and found the problems easy, while others may have not yet learned the content and found problems more difficult. Second, in neither the app nor paper sessions were students provided with a review of the mathematics concept prior to being asked to solve word problems using that concept. A brief introduction in which the mathematics concept was reviewed might have been valuable. Third, teachers were asked to rate the student in multiple areas (for example, motivation and assistance with graphics). One person might define “a little bit of help” one way and another person might define that same amount of help as “a lot of help.” Although examples were provided in the online training for the teachers, variation still was possible, and ratings may have been influenced by teachers’ beliefs about the value of assistive technology. Fourth, for print readers, materials were prepared using 18-point Verdana font. Some print users may be more efficient with a smaller font size while others may be more efficient with a larger one. The project resources did not allow for materials to be prepared in the specific print size and font style each student typically used.

As noted earlier, about students’ use of the iPad’s ability to play the text of the introductory material, problems, hints, and so forth: We do not know if some students opted to not use audio because they did not know it was an option, found it distracting to their reading of print or braille, or were efficient with their own reading abilities in either print or braille. We also do not know how many students paired the audio with reading in their primary literacy medium.

Finally, the major limitation of the study is that we do not know if hints would have helped students when they worked on paper units. Our primary research question was about the potential of interactive technology to support students' independent problem solving relative to current practice in which they typically would not have hints. In addition, if hints had been included in the paper units, it would not have been possible to control when a hint became available (that is, after at least one incorrect attempt) or to record whether the student accessed it or not. Thus, although the results suggest that the hints were helpful when students worked with the app, it is difficult to make a direct comparison with their performance on the paper units because the technology afforded a different form of interaction.

FUTURE IMPLICATIONS

The study results suggest the promise of using assistive technology to provide instruction and reinforcement to students learning pre-algebra mathematics skills. Future work that provides additional content to users would be valuable. During both student and teacher interviews, suggestions were made that included adding other science-related content, allowing teachers to input their own material, having the interface be more "game-like," and adding instruction and examples to units. In addition, it became apparent in the study that many visually impaired students are not as efficient as they could be when gathering information from graphics, be it in print or braille (Zebehazy & Wilton, 2014a, 2024b). There is currently no curriculum to teach visually impaired students strategies for gathering information efficiently. Future work should address this need. A future study that looks at the way in which audio is used as either the primary way to access information or in tandem with a student's primary literacy medium is needed.

We live in a time in which technology has the potential to provide visually impaired individuals and those with other disabilities with access to curriculum so they can learn alongside their nondisabled peers. Educators and developers must have a commitment to make the technology accessible, motivating, and instructional. Through this project, we have shown that visually impaired students can build their pre-algebra skills and ultimately be more successful in mathematics classes through the use of such technology.

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