Use of an Accessible iPad App and Supplemental Graphics to Build Mathematics Skills: Feasibility Study Results

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Structured abstract: *Introduction:* The present study evaluated the feasibility of using an iPad application or "app" for algebra-readiness mathematics, with accompanying braille materials and accessible graphics, when used in authentic educational settings. *Methods:* Twenty-nine students with visual impairments in grades 4–11 used the materials under the direction of their teachers of students with visual impairments ($N = 19$). Twenty percent of the mathematics problems included graphics such as maps, line graphs, and bar graphs. Students and teachers of students with visual impairments provided feedback about the feasibility of using the app with supplemental materials, and made suggestions for additional features to improve the instructional package. *Results:* Students completed 984 word problems and solved 80% of them correctly within three attempts. The use of some features such as hints and "worked-example" videos was low. Participants provided suggestions for improvement of the app features and accessible graphics. *Discussion:* Students and teachers of students with visual impairments were able to use the materials successfully, and comments were generally positive. Participants' comments and suggestions were used to revise the app and materials. *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.

Mathematics can be challenging for many students, regardless of whether they have disabilities. Educators and researchers have noted, however, that mathematics is often especially difficult for students with visual impairments (McDonnall, Geison, & Cavenaugh, 2009). In particular, algebra has been identified as a critical "gatekeeper"

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course (Atanda, 1999; Moses & Cobb, 2001; Silver, 1995). Students who do not pass algebra are not likely to qualify for programs of study that lead to science or engineering careers, and they face limited employment opportunities (Chazan, 2008; Goertz, van Lierop, Houkes, & Nijhuis, 2010; National Science Foundation, 2013; Stein, Kaufman, Sherman, & Hillen, 2011). Often, the problem is that students lack proficiency in key algebra-readiness skills such as division, fractions, decimals, and unit conversion (Tolar, Lederberg, & Fletcher, 2009).

The present project was designed to help visually impaired students build their algebra-readiness skills by making an existing web-based tutoring program accessible. The web-based program, AnimalWatch, had been previously developed by the lead author with support from the U.S. Department of Education. The program was selected for this project for two reasons.

First, prior work indicated that sighted students in classes that used the AnimalWatch program scored higher on a range of learning outcomes, including an end-of-year state mathematics achievement test as well as study-specific measures, than comparable classes that did not use the program (Beal, Arroyo, Cohen, & Woolf, 2010; Schneider et al., 2014). Students who worked with the AnimalWatch program benefited from receiving immediate feedback about the accuracy of their work and from the interactive hints and solutions or "worked examples." In contrast, traditional worksheets and homework assignments need to be graded, and students who work from these traditional methods do not necessarily receive feedback in a timely manner and may not have the opportunity to learn what they did wrong or how to solve problems correctly.

Second, the AnimalWatch program focused primarily on mathematics word problems. The ability to solve such word problems has long been considered to be a key indication of mathematics proficiency (Koedinger & Nathan, 2004). More recently, the influential Common Core Mathematics Standards have placed additional emphasis on students' ability to solve mathematics word problems as an indication of their understanding of key mathematical concepts (www.corestandards.org/math).

In its original form, AnimalWatch was a web-based program that was not readily accessible to visually impaired students. Some components of the web interface involved the Flash Player, which often proved to be challenging when used with screen reading software. Additional supports such as image descriptions were needed. Several teachers of students with visual impairments also pointed out that it would be helpful to include background information about the endangered and invasive species that were the topics of AnimalWatch units.

Product development

The original plan had been to adapt the web-based AnimalWatch program for students with a range of visual abilities to increase its accessibility. At the time of the project launch, however, the rapidly growing interest in the use of handheld electronic devices created by Apple (also known as iDevices) in both general and special education was becoming evident (Zhou, Parker, Smith, & Griffin-Shirley, 2011). These and similar devices are relatively inexpensive and portable, and

include many built-in accessibility features. In addition, several teachers of students with visual impairments had mentioned to the project team members that such tablet devices have a "cool factor" that is appreciated by many adolescents with disabilities who want to "fit in" with peers. Thus, the research team began to consider the idea of developing an accessible iPad application or app version of AnimalWatch as an alternative to the web-based software.

To inform the development decision, the research team conducted an online survey about various instructional platforms, including desktop computers, smartphones, and tablets. The survey was opened in spring 2012 to teachers of students with visual impairments. Participants were asked to answer the questions in relation to visually impaired youths in grades five to nine who were within one grade level in mathematics. Responses from 88 teachers of students with visual impairments from 27 U.S. states suggested the iPad platform—which includes Apple-proprietary accessibility features such as VoiceOver (an integrated speech option)—as the technology that held the most potential for future classroom use. Thus, the researchers decided to develop an iPad app for the AnimalWatch content, including accompanying materials to support classroom use. Together, the app and materials form an instructional package referred to as the "AnimalWatch Vi Suite" (AWViS).

Features of the AnimalWatch Vi Suite

At the time of the present study (January to April 2014), the AnimalWatch Vi Suite iPad app included 12 mathematics units covering topics such as operations with positive and negative integers, fractions, decimals and percentages, and unit conversion. Each unit included six word problems about a particular endangered or invasive species, such as the snow leopard, sea turtle, black rhino, and poison frog.

Each word problem included two hints that were available on request to the student, and a short video showing a worked example of a similar problem involving the same mathematics operation. Two problems in each unit included graphical information such as maps, bar graphs, and line graphs. Examples of word problems with and without graphics are shown in Boxes 1 and 2.

The graphics were produced in either print or braille format; all included the use of color and texture to provide users with the option to use any combination of visual or tactual access desired. In addition, the app contained an audio description of the graphic including its title and pertinent features (for example, the labels for the x and y axes and the number of bars in a bar graph). In addition, each unit included an introduction with a graphic of the species that formed the theme for the unit. These graphics included color, texture, and either braille or print labels; audio descriptions of graphics were available in the app that noted key features of the animal. For example, the graphic of the poison frog included an embossed, life-size image of a paper clip to support the point made in the audio description that these frogs are typically smaller than a paper clip. All graphics were also visible on the screen within the app.

The app allowed students to access audio for all text on the screen by either using VoiceOver or a two-finger single

Word problem example with graphic

Sea Turtle Unit B: Using fractions to solve problems

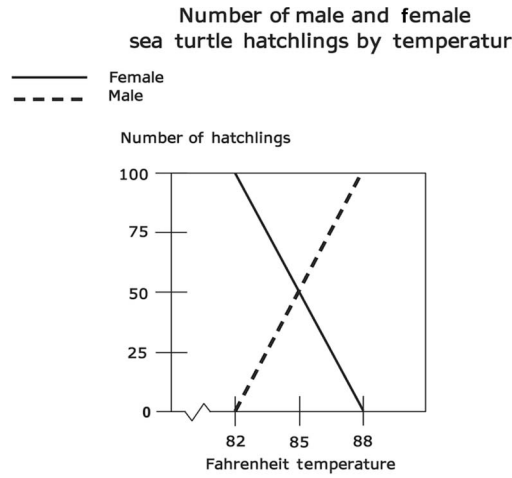
Common Core Curriculum Standard Grade 5 Number & Fractions B.6. Solve real-world problems involving division of unit fractions by non-zero whole numbers and division of whole numbers by unit fractions (such as by using visual fraction models and equations to represent the problem).

Problem with graphic. The line graph shows how the sex of sea turtle hatchlings depends on the temperature of the sand nest. Warmer sand means that more hatchlings will be female, and cooler sand means that more will be male. Use the graph to find the temperature at which half of the hatchlings in a nest of 100 eggs will be female and half will be male.

Hint 1. Find 50 on the vertical axis, then check where the lines cross.

Hint 2. Follow the cross point down to the horizontal axis to find the temperature at which there are equal numbers of males and females.

Answer. 85 degrees



Box 1

tap, which activated the app's internal speech (designed to sound similar to VoiceOver). Areas of the screen could be enlarged using the built-in Apple accessibility feature Zoom. A settings page within the app allowed students to select a font color and background combination to maximize usable vision, to fade or eliminate artwork (such as a decorative border that illustrated the habitat of the currently active species), and to adjust the audio speed if using the app's internal speech.

The Enter Answer Pad was an area within the app that allowed students to enter answers and receive immediate feedback. Students with severe visual impairments used the enter answer pad to input their answers.

Word problem example without graphic

Sea Turtle Unit B: Using fractions to solve problems

Common Core Curriculum Standard Grade 5 Number & Fractions B.6. Solve real-world problems involving division of unit fractions by non-zero whole numbers and division of whole numbers by unit fractions (such as by using visual fraction models and equations to represent the problem).

Problem. The sea turtle breathes air. If it is caught in a fishing net and cannot get to the ocean surface, it can drown. To help sea turtles, fishermen have started to add special openings to their nets that let the sea turtles escape. Marine biologists found that 4/5 of the sea turtles caught in one net were able to escape using the openings, but 12 turtles were not. How many turtles in all were caught in the net?

Hint 1. You know that 1/5 equals 12 turtles. Multiply 12 by the total number of parts.

Hint 2. Multiply 12 times 5 to find the total number of turtles that were caught in the net.

Answer. 60 sea turtles

Box 2

The Enter Answer Pad was linked to a moveable Scratch Pad: a manipulatable area within the app that could be repositioned and allowed those with usable vision to use finger gestures to write computations on it. Features of the scratch pad allowed the student to adjust the line thickness of the pen, undo the last pen stroke, or erase the page.

The app also included: a glossary that provided definitions of words used in the four introduction pages, word problems, and conclusion page; brief text hints that could be accessed on request; and videos showing worked examples that students could view on request. The videos were designed so that the narrator described what she was writing on the screen as she worked the problem so that students who could not see the screen would be able to follow along with the steps.

Accompanying materials included brailled copies of all the text on the screens of the unit. All braille materials were prepared in Nemeth Code for Mathematics and Science Notation (hereafter, Nemeth). Although in theory all information would be available in audio format to the student within the app or on a refreshable braille display if the student was using one, it was recognized that students might prefer to access information in hardcopy braille. In addition, the app used synthetic speech generated from the text, which sometimes led to unusual pronunciations; the brailled copies could serve as a potential reference for clarification in such cases. For example rather than saying "one-fourth," VoiceOver says "one slash four," which can be confusing to a student.

All app content and accompanying materials were reviewed and approved

by members of the project's advisory team, which included two experts in mathematics education for visually impaired students, a certified braille transcriber who is a retired teacher of students with visual impairments, an experienced teacher of students with visual impairments, and a high school student who is a braille reader. During the development of the app and accompanying materials, initial usability feedback was also obtained from 30 visually impaired students who worked with prototype versions in sessions directed by researchers. All materials were aligned with the Common Core Curriculum Standards for Mathematics (see Boxes 1 and 2).

Goals of the study

The study goals were, first, to learn if the app and accompanying materials could be used successfully by students and teachers in their typical school situation. Second, we sought additional feedback regarding potential improvements.

Methods

Participants

The study included a convenience sample of 29 visually impaired students (14 males, 15 females) and 19 teachers of students with visual impairments, who were recruited from schools and programs throughout Arizona. The students included 15 print users and 14 braille users. The grade level of students ranged from 4th to 11th grades. The research was reviewed and approved by the Institutional Review Board of The University of Arizona.

Teacher training

Teachers who had been recruited for the study were provided with initial information about the iPad, its accessibility features, and ways to use it within general education classrooms. Teachers then attended a three-day training workshop. Two hours of the training were spent on a walk-through of the AWViS and the study procedures. Three hours of the training focused on how a student who is blind can use a refreshable braille display with an iDevice. At the start of the study, only five students had had experience using braille displays with such devices.

Teachers then returned to their schools and introduced the app and materials to their students in their typical classroom situations. Students started with a training unit designed to provide an overview of the features of the app and an opportunity for them to customize the app's settings to maximize their access. The training unit included three easy-to-solve word problems intended to orient the student to the problem interface and the procedures for entering their answers. For example, one problem was designed to tell the student how to use a slash to enter a fraction. Another explained that to enter a mixed number, the student should include a space between the whole number and fraction.

In the following weeks, students then completed up to six mathematics units selected by their teachers of students with visual impairments. Some students who were blind used refreshable braille displays with the devices. Data about problem solving was automatically recorded in the app and transmitted to the researchers via the Internet. Because Wi-Fi

Table 1
Mean number of correct answers on first, second, and third tries.

User	Correct 1st try	Correct 2nd try	Correct 3rd try	Strikeout	Give up
Print users	3.56	0.91	0.33	0.64	0.49
Braille users	3.42	1.04	0.41	0.63	0.46
All users	3.50	0.95	0.36	0.64	0.48
	$t(16) = 1.00$, $p = 0.921$	$t(16) = 0.639$, $p = 0.532$	$t(16) = 0.447$, $p = 0.665$	$t(16) = 0.150$, $p = 0.881$	$t(16) = 0.206$, $p = 0.838$

connections were not always available in some school settings, the app was programmed to transmit the data when a connection was detected (for instance, at the home of a teacher).

Interviews

After the target number of sessions had been completed, both students and teachers of students with visual impairments provided feedback to members of the research team via a telephone interview. Interviews were conducted separately for teachers of students with visual impairments and students. Comments and suggestions gathered from the interviews were compiled and grouped by topic to guide future improvements to the app and materials.

Results

Completion of mathematics units

Students completed an average of 5.65 units each (not including the training unit). Twenty-one students completed six units, six students completed five units, and two students completed four units. There was no difference in unit completion for students as a function of reading medium (print or braille), $t(16) = 0.254$, $p = 0.599$.

Data about how the students performed on the mathematics problems is shown in Table 1. There were no significant differences with regard to problem outcomes (correct or incorrect answers) as a function of reading medium, $t(16) = 0.311$, $p = 0.379$. As may be seen in the table, students solved most ($M = 4.81$) of the six problems in a unit within three attempts, and they rarely chose to give up on a problem ($M = 0.64$).

Use of app features

The average number of times per unit that students accessed app features such as hints, videos, and the Scratch Pad was computed (note: there was no limit to how often students could use these features). There was no difference in the mean number of times the glossary was accessed per unit ($M = 0.27$ for both print and braille users). Print readers used more hints ($M = 7.10$) than braille users ($M = 5.26$), but the difference was not significant, $t(16) = 1.141$, $p = 0.886$. Those who read print were more likely to view the videos ($M = 0.633$) than were those who read braille ($M = 0.18$), $t(16) = 2.396$, $p < 0.5$. Viewing of the videos was significantly correlated with hint use (pairwise $r = 0.536$), although overall the use of both features was low. Not surprisingly, print users were more likely to use the Scratch Pad than were braille readers: $t(16) = 6.553$, $p < 0.001$.

Interviews

Comments and suggestions from students and teachers were organized around specific app features, as outlined next. In general, teachers and students expressed similar views.

Audio controls

Students who used the built-in audio capabilities of the app indicated they would prefer to have more options to control the audio. Four students thought that hearing the answer feedback sounds ("sorry," "correct") should be an option in settings. One student did not like the app's synthetic speech, and another thought that there should be a choice of voices. Two suggested that there should be a global control to turn off all audio. Options to hear audio while using Zoom to enlarge the text, or to turn off all audio except for the image descriptions, were mentioned by two students.

Enter Answer Pad

Many students had suggestions about the layout and features of the Enter Answer Pad. Three students thought that the numbers should be arranged in telephone keypad order (1, 2, and 3 in the top row) instead of calculator order (1, 2, and 3 in lower row). Six students questioned the abbreviation "SPC" for "space" and suggested that the complete word be written out on the button. Five students thought that the Enter Answer Pad should include more audio (for instance, an alert sound when it opened, numbers spoken when entered or deleted). Other suggestions included making the buttons more obvious with thicker lines or color contrast, and more indications that the Enter Answer Pad was open on the screen (such as a change in color on the "enter answer" button or an alert audio signal upon opening). One student requested an option to submit answers by using speech, and two wanted to submit answers using a refreshable braille display.

Scratch Pad

Three students suggested that the Scratch Pad be moveable, and another mentioned that when opened, the Scratch Pad covered up the problem text, making it difficult to refer to the problem. One student suggested that there should be icons for the Scratch Pad's pen, erase, and hide features.

Glossary

Seven students indicated that the definitions should be available in audio format, one did not think that the addition of audio was necessary, and one thought that making audio available for the glossary items should a global option on the Settings page. One student suggested the button for the feature should be labeled "Dictionary." Three students thought that the words in the glossary should be highlighted in the text on the screen. One suggested the option of tapping a word in the text to hear the definition.

Hints

The concept of hints to accompany the word problems was reported to be valuable, but students commented that the quality of the hints was inconsistent. One student thought that hints should not be available until at least one answer attempt had been entered. Six students thought

that users should have to enter at least one answer before the "give up" option became available.

Videos

Students reported some uncertainty about how to control the videos (for example, start, stop, and pause) and how to navigate away from the video back to the problem. One student mentioned that when the video was enlarged with Zoom, the pause button became difficult to see. Another noted that the navigation button to return to the problem was gray, incorrectly implying that it was not active. One student thought it would be helpful to have a print copy of the video screens.

Eight students reported that the videos were too long, contained too much information, and were too generic (that is, not specific to the problem that the student was trying to solve) to be useful. One teacher commented, "It would be more helpful to see steps on how to get the answer so then on the next problem she might be able to do it." Four students thought that a "solution" video explaining how to solve the problem should be available if the student gave up or entered three wrong answers.

Graphics

Students had the option of viewing graphics on the iPad or in hardcopy (braille or print). Students with low vision almost always chose to look at the graphics in the book rather than on the iPad screen. Several teachers and students commented that the size of the graphics on the iPad screen made visual access to them difficult, while the graphics in the book were easy for them to read. Several teachers commented that the tactile component of the print graphics was appreciated by the students with low vision even though they were using vision as their primary sensory channel to access information.

For graphics with bar graphs, five students said that the bars should be solid, but three felt that texture marks in the bars were acceptable. One student pointed out that it should be easy to distinguish a gridline from a line in a line graph. Three students noted that it was easy to confuse lines in a line graph, and suggested using different colors or shapes (for instance, a circle or triangle) to help distinguish multiple lines. Three thought gridlines for graphs should be solid, five thought they should be dotted, and two preferred light gridlines. For maps, students did not like the texture used to indicate the ocean; six thought the ocean area should be blank or a solid color, and two said the border separating the continents and ocean should be thicker.

Use of the hardcopy braille or refreshable braille display

Variability was reported in how often students used the hardcopy braille or a refreshable braille display to access the app. Some students obtained a refreshable braille display during the study and were just learning to use one. Generally, students who were braille readers reported listening to the problems most of the time. When the braille copy was used, it was typically to clarify information that was heard or because the student wanted to examine the problem with his or her fingers.

Discussion

The present study was designed to assess the feasibility of use of the AnimalWatch Vi Suite instructional package in authentic

educational settings by visually impaired students and their teachers of students with visual impairments. In general, the effort appeared to be reasonably successful. Teachers of students with visual impairments were able to introduce the app and materials to their students and supervise four to six sessions over the next few months. Students quickly learned to navigate through the app by using the brief training unit, and were able to solve many of the mathematics word problems successfully. It should be noted that, in general, the students were already familiar with iDevices, and that the teachers of students with visual impairments had participated in a professional development program about the accessibility features of the iPad. Results might have been different for users who were using an iPad for the first time.

The feedback from students and teachers of students with visual impairments was used to develop a plan to revise the app and materials. The biggest changes involved making the instructional supports within the app more interactive and more specific to each problem. The generic worked-example videos were replaced with brief screen-capture videos that showed the specific steps for solving each of the problems. The research team also rewrote the hints to ensure consistency of the hints for all problems. The first hint now indicates the mathematics operation to be used for the problem, and the second hint includes the numbers to be used in the problem equation. The hints now appear automatically in response to incorrect answers and give students the option of hearing them.

Some problems identified in the study remain unresolved. Several students reported that they were bothered by the iPad's occasional mispronunciation of words. For example, the word "live" was sometimes (incorrectly in the context) pronounced with a long "i" sound (as in "alive"). Users and project advisors also noted that the app does not pronounce fractions properly, as previously noted. Unfortunately, the solution for mispronunciation is not obvious at this time. Prerecorded speech could be used for common fractions (such as 1/4, 1/3, 1/2), but it would be considerably more challenging to provide a general solution that could accommodate pronunciation of any possible fraction (for instance, 39/153).

Another challenge became apparent during the interviews for the few students who reported (or whose teachers reported) that they used refreshable braille displays. Although the iPad operating system was described as supporting Nemeth, students reported that the Nemeth they saw on their braille displays was not accurately produced. For example, numbers were placed in the upper part of the braille cell rather than in the lower part of the cell. Although of concern to the research team and project advisors, the technological resolution to the problem regarding Nemeth output was determined to be beyond the scope of the project. As the project has moved forward into the dissemination phase, plans are under way for the braille materials including the tactile graphics to be available both in Nemeth code and Unified English Braille (UEB); however, the mathematics displayed on the app will continue to only be available in UEB.

Future research

The next step in the project will be to explore the extent to which AWViS can help

to prepare visually impaired students to be ready for algebra. A study to compare the progress of students with the app and its materials to their progress with materials in their traditional literacy medium would help to determine the value of technology as a potential tool to support mathematics learning by those students.

Implications

The importance of accessibility in technology-based education is receiving increased recognition (McGraw-Hill, 2015). However, there continues to be room for improvement. For example, the U.S. Justice Department recently reported that a major provider of online education had not made its courses accessible to visually impaired students or those with other disabilities (Fabris, 2015). The use of iDevices and other tablets with integrated accessibility features is likely to increase in elementary, secondary, and higher education settings. It will be increasingly important to ensure that teachers of students with visual impairments have the knowledge base to provide instruction in such devices to their students so they can use these tools in the classroom to participate alongside their sighted peers.

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