An Assessment-for-Learning System in Mathematics for Individuals with Visual Impairments

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Abstract: This study examined the usability of an assessment-for-learning (AfL) system that provides audio-tactile graphics for algebra content (geometric sequences) for individuals with visual impairments—two who are blind and two with low vision. It found that the system is generally usable as a mathematics AfL system.

There is a great potential for using assessment-for-learning (AfL) systems to improve the ability of students to learn. Such systems integrate learning with assessment and typically provide educational experiences in the context of assessment (Bennett & Gitomer, 2009; Quellmalz & Pellegrino, 2009; Razzaq & Heffernan, 2006; Shute, Hansen, & Almond, 2008). However, it is critical that the benefits of such systems are available to diverse individuals, including those with disabilities (Hansen, Forer, & Lee, 2004; Individuals with Disabilities Education Act, 2004). Unfortunately, assessments are often designed without taking accessibility into account from the beginning, resulting in a lost opportunity for students with disabilities to learn. With support from the National Science Foundation, researchers at the Educational Testing Service (ETS) developed an AfL system and attempted to take the accessibility needs of individuals with visual impairments (as well as sighted individuals) into account from the earliest stages of its development. Such systems, if successful, may greatly improve learning and equal-access opportunities for students with visual impairments.

The system, called Adaptive Content with Evidence-based Diagnosis (ACED)

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was designed to assess and support the learning of algebra. ACED is an AfL system in that it seeks to leverage information obtained during assessments to enhance students' learning (see Shute, Graf, & Hansen, 2005, for more details). ACED provides an innovative combination of elaborative feedback for incorrect answers (such as providing an explanation of how to solve the task correctly and sometimes an explanation of why the student's answer was incorrect) and the adaptive sequencing of tasks (Wainer et al., 2000). An evaluation of ACED with 268 sighted students indicated that the combination of elaborative feedback and adaptivity was effective for learning. It appears that the learning effect was due largely to the effect of feedback (see Shute et al., 2008).

This article reports on a small study of the usability of ACED with four individuals with visual impairments—two who are blind and two with low vision. The focus of the study was on how easily the participants could interact with the system.

The population of individuals with visual impairments is diverse, and a small-sample usability study such as this can provide results that are only suggestive of results that would be obtained with larger or more representative samples. However, according to Nielsen (2000), a low number of users can be helpful to a study like this because 5–10 users is often sufficient to find 80% of usability problems.

Method

Sample

The sample consisted of four students (S1, S2, S3, and S4), two males and two females aged 17–20. An institutional review board (the Committee for Prior Review of Research) at ETS in Princeton, New Jersey, approved the study, and informed consent was obtained from the participants. All the participants were high school students and had either an Individualized Education Program or a Section 504 plan for individuals with visual impairment. Although all four students were considered legally blind, two had some useful vision (S1 and S2), and the other two had essentially no usable vision (S3 and S4). S1 and S2 reported using "large print or enlargement of print or pictures" as their primary method for study and learning, and S3 and S4 reported using "hearing and touch and can read braille." A summary of the descriptive characteristics of the four participants is presented in Table 1.

The ACED system

The following is a summary of the main features and functionality of the capabilities of ACED.

Three modes

To provide access to ACED for students with and without visual impairments, ACED provides three distinct interfaces or modes: regular mode, low vision mode, and blind mode.

Regular mode

The regular mode was used in the larger study with sighted students (Shute et al., 2008). This mode uses regular-sized fonts and provides no speech output. It operates on a computer monitor with a keyboard and optional mouse.

Table 1
Characteristics of the participants (S1, S2, S3, S4).

Characteristic	S1	S2	S3	S4
ACED mode used	Low vision	Low vision	Blind	Blind
Gender	Male	Female	Female	Male
Age	17	19	20	18
Born in the United States	Yes	No	No	Yes
Grade began attending school in the United States	K	9th grade	9th grade	K
"I like mathematics as a subject area in school"	No	No	Yes	No
Latest grade attained in math class	Satisfactory	80%	87%	80%
Uses a screen reader	No	No	Yes—JAWS	Yes—JAWS
Uses large-print test booklet in school	Yes	Yes	No	No
Had used a human reader in school	Yes	Yes	Yes	Yes
Uses braille to take tests	No	No	Yes	Yes
Uses raised-line drawings to take tests	No	No	Yes	Yes
Preferred media for math	Talking calculator	Calculator with enlarged font. CCTV (closed circuit television)	CCTV for diagrams, Nemeth braille code. Tactile graphics and scribe for testing	Perkins Brailler and math in Nemeth braille code
Use of a computer	2 times a week	2 times a month for 2 years	Use Braille Lite (electronic notetaker) every day, a computer once a month	Daily, for 9 years

Low vision mode

The low vision mode is similar to the regular mode, except that (1) the text and pictures can be magnified; (2) it provides prerecorded speech to voice the navigational instructions and all math content; and (3) speech synthesis is used only to echo the characters that are typed in via the keyboard for constructed-response (open-ended) questions and the like, thus emulating the operation of screen-reader software that individuals with visual impairments, especially those who are blind, often use. The students could choose to use the low vision mode with or without audio. The low vision mode was designed to be operated through a computer keyboard alone or supplemented by the use of a mouse. When the students used magnification, they essentially saw an enlarged version of a portion of the screen that is visible in the regular mode and could access the parts that were off the screen by panning the image up, down, left, or right. They could also set the level of magnification and the select the color scheme for the text or desktop background display.

Blind mode

In most respects, the blind mode is similar to low vision mode except that it also uses the Talking Tactile Tablet (TTT), manufactured by Touch Graphics, which is designed to allow a student to touch a tactile (raised-line) graphic or a feature of it and immediately hear (via prerecorded speech) about that graphic or feature. Thus, as with the low vision mode, the blind mode includes human-voice recordings of navigational instructions and all math content, and synthesized speech is used only to relay responses that are typed using a keyboard. The computer application plays the appropriate audio messages to prompt a student who is blind to log in to the system, set user preferences, move through items, enter responses, and listen to feedback. The blind mode operates with a rectangular touch-sensitive tablet that is about 12 inches × 15 inches in dimension. A plastic overlay sheet with raised-line elements (graphics, text, and braille labeling) and color printing (for those with residual vision) is placed on the tablet and secured into place so that the sheet does not slide. TTT is connected to a laptop computer via a USB port, and it enables the computer to interpret a user's touch on the tactile overlay sheet as if a mouse had been clicked over that area. The system is designed to guide the user via audio in how to set up successive items as required by the adaptive sequencing algorithm. When a student touches the tablet, the location of the touch is sent to the computer, which then invokes actions, such as voicing the content or instructions. The blind mode also echoes letters and words in synthesized speech as they are typed to guide the user in entering constructed responses. Students can choose a voice, set the rate at which speech plays, and customize the touch sensitivity of TTT.

Determining which mode to use

ACED provides an administration utility to guide the student to one of its three modes to configure the system to user preferences in the areas of read-aloud (the prerecorded human voice) or silent, the speech rate for the synthetic voice that is used to echo letters and words as they are typed in for open-ended responses, the screen-magnification level (non-TTT only), the text or background color scheme (non-TTT only), and tactile sensitivity (TTT only). This utility takes the form of a series of screens that allows the student to make choices that allow the computer to deduce how to configure access features most effectively. Once ACED assessment has begun, the user can revise earlier settings.

Additional key capabilities

The system features additional capabilities. Students, whether visually impaired or sighted, can use a standard keyboard to type in answers to constructed-response questions. In addition, ACED maintains two modes of feedback (elaboration and verification), two modes of task sequencing (adaptive and linear), and, under the control of the researcher or proctor, can administer tasks in any combination of modes and with or without TTT. Other capabilities include help and tutorials on how to read and interpret audio-tactile groups, exit the test, and return to the test (after using help or adjusting the settings).

Content

As with the larger study with sighted students (Shute et al., 2008), the study presented here involved geometric sequences (that is, successive numbers linked by a common ratio). The tasks that were used in the current study consisted of a pool of 30 items, selected from the pool of 63 items in the larger study for sighted individuals. The reason for the reduction in the number of tasks was to ensure that a significant proportion of the items that the participants viewed would involve graphics and tables, thereby providing a basis for evaluating the audio-tactile features of TTT during the study.

Assessment design

Before the study began, all the content was reviewed to avoid task designs in which the nature of the accommodation would conflict with the purpose of the assessment (Hansen & Mislevy, 2005; Mislevy, Steinberg, & Almond, 2003).

Instruments

Geometric sequence items, using adaptive sequencing. ACED was designed to administer up to 30 items in either of two modes—low vision or blind. A series of set-up screens guide the user in configuring the system for the two modes and in configuring the audio (pitch and speed), font size, color of text or background, and so forth. Both modes used a laptop computer with audio-output capabilities (speakers). Tasks were administered adaptively using the same adaptive algorithm discussed earlier, so each participant generally received a different set of tasks during his or her time on ACED. Tasks differed as a result of each student's particular solution history.

Pretreatment survey. This survey posed questions about the students' backgrounds (such as disability and language spoken at home), experience with assistive technologies, accommodations in school, and so forth.

Posttreatment survey. This survey gathered information about the students' reactions to using ACED.

Procedure

Testing of the four participants took place at the Touch Graphics office in New York City. The participants worked individually during each session. The first two authors conducted the sessions, including the pre- and posttreatment interviews, and coded and tabulated the results. The following is the basic procedure that was used.

Pretreatment survey and introduction

The pretreatment survey questions were administered via interviews. The students were informed that the purpose of the study was to evaluate the system, rather than to evaluate their knowledge of mathematics. Nevertheless, they were asked to do their best in answering the questions when using ACED.

Familiarization and system configuration

Each student received a computer-based tutorial on the use of ACED and was guided by the system in selecting the system options. The students generally required little help in using ACED. Participants S1 and S2 used the low-vision mode of ACED, and participants S3 and S4 used the blind mode of ACED.

Assessment tasks and feedback

The students used ACED with elaborative feedback and adaptive sequencing. The intent was to allow each student about an hour to become familiar with and use ACED. Because of transportation and other logistical issues, however, the amount of time during which participants were allowed to use the system was curtailed to 40 to 48 minutes for three of the four participants; the fourth person took 72 minutes.

Posttreatment survey

Each participant received a posttreatment survey that was administered during an interview.

Results

The results of the usability study are presented in four parts: (1) basic usage data describing what the students did on ACED and how they performed using both the low vision and blind modes of ACED, (2) the overall usability of ACED in relation to important features of the system, (3) students' specific reactions to the low vision and blind modes of ACED, and (4) the strengths and weaknesses of the system in relation to the students' responses regarding what they particularly liked and did not like.

Use of ACED

Table 2 presents the basic data on the use of ACED for the four participants. The amount of time taken for familiarization and configuration of the system was longer for the students who were blind (47 minutes for S3 and 25 minutes for S4) than for the students with low vision (19 minutes for S1 and 12 minutes for S2). The students who were blind were using TTT and therefore had to take some time to become familiar with its interface and to configure it. Also, as is shown in the last line of the table, the students took from 1.3 to 3.5 minutes to complete each item (including feedback), compared to roughly 1 minute per item for the sighted students in the previous study who used the regular mode of ACED (about 60 minutes to complete 63 items) (Shute et al., 2008). This difference is consistent with the expectation that students with disabilities who use assistive technology generally need more time to access content.

Use of the low vision mode

Participants S1 and S2 used the low vision mode of ACED (which operated

Table 2
Time, items, and percentage correct.

Participant	S1	S2	S3	S4
Modes used	Started in sighted mode and then switched to low vision mode with audio	Started in low vision mode with audio and large font and then switched to medium font	Blind mode	Blind mode
Time for familiarization and configuration (in minutes)	19	12	47	25
Time answering items and receiving feedback (in minutes)	29	28	25	16
Total time using system (in minutes)	48	40	72	41
Items completed	9	8	9	12
Correct responses	1	5	4	8
Incorrect responses	8	3	5	4
Percentage correct (of items completed)	11	63	44	67
Average time per item completed (in minutes)	3.2	3.5	2.8	1.3

with a laptop but not a TTT). S1 initially entered the program in the regular mode but changed to the low vision mode with audio within 1–2 minutes. He listened to the questions with synthesized speech as he read along and looked at the graphics on the screen. He used a handheld calculator, rather than the on-screen calculator that was available in ACED. As Table 2 shows, S1 required 19 minutes to familiarize himself with and configure the system, followed by 29 minutes to answer the items and receive feedback. He completed 9 items and answered only 1 correctly, which may be indicative of an access issue or the lack of prerequisite knowledge of the system or of the math content.

S2 used the low vision mode with magnification, but because of her inexperience with screen-enlargement software and computers in general, found it difficult to navigate ACED. She then decided to return the magnification level to a "normal-sized" font, used the audio, and moved the screen close to her eyes to examine the onscreen graphics. S2 preferred to use the Tab key to move from item to item instead of the mouse, but she did use the mouse several times. In the beginning, she expressed some frustration, but after several minutes and as a result of the instructional feedback, she appeared to recall the idea behind geometric sequences and was subsequently able to answer several questions correctly. She used a large-print calculator and scratch paper to solve the problems. After the session, S2 asked, "How can I get this in school? It's great!" As Table 2 indicates, it took her 12 minutes to familiarize herself with and configure the system, followed by 28 minutes to answer items and receive feedback. S2 completed 8 items and answered 5 correctly.

Use of the blind mode of ACED

Participants S3 and S4 used the blind mode of ACED, which uses the TTT. They pressed on the TTT to hear the meaning of various parts of the plastic overlay sheet. S3 and S4 took longer to

Table 3
Students' agreement with statements about ACED features.

Statement	S1 Low vision mode	S2 Low vision mode	S3 Blind mode	S4 Blind mode
ACED was easy to use	A	A	A	A
The synthesized speech in the screen reader was easy to understand	A	A	A	A
I liked using the speech feature to have the test read aloud	SA	SA	Not asked	Not asked
It was easy to use the [ACED] screen reader for questions requiring a keyboard	A	A	A	A
It was easy to type in short numerical answers on the computer keyboard	A	A	SA	SA
In was easy to understand the tables (row headings, column headings and cells) using the system	SA	A	SA	SA
When my answer was wrong, the system helped me understand why my answer was wrong	A	SA	SA	A
Having used the system during this session, I think that I now know how to use the system well enough to use it for an important test	N	SA	A	A

Note: SA = strongly agree; A = agree; N = neither agree nor disagree; D = disagree; and SD = strongly disagree.

familiarize themselves with and configure the system than did those who used the low vision mode (S1 and S2). This difference is understandable because of the greater number of special accessibility features in the blind mode. S3 had some difficulty at the beginning of the session, since she was unfamiliar with geometric sequences as well as the TTT. She answered the first two items incorrectly. She was apparently helped by the instructional feedback and answered the next four questions correctly in a row. As Table 2 shows, S3 required 47 minutes to familiarize herself with and configure the system, followed by 25 minutes to answer items and receive feedback. She completed 9 items and answered 4 of them correctly.

S4 had been exposed to TTT about three years earlier and therefore skipped some of the basic TTT introductory tutorial. He also selected a different synthesized voice ("Alice" as opposed to the default voice "David") and increased the speech rate. As Table 2 indicates, he took 25 minutes to familiarize himself with and configure the system, followed by 16 minutes to answer questions and receive feedback. He completed 12 items and answered 8 correctly.

Overall usability

All four students completed a survey at the end of their interaction with ACED, indicating the degree to which they agreed or disagreed with various statements that were read to them. Table 3 summarizes the students' responses, coded as strongly agree, agree, neither agree nor disagree, disagree, and strongly disagree.

As can be seen in Table 3, all four participants agreed that ACED was easy to use and that the synthesized speech was easy to understand. Understanding the audio was critical for those who used the blind mode. The use of the audio feature was optional in the low vision mode but was invoked by the two participants who used that mode, both of whom strongly agreed that they liked using the speech feature to read the assessment aloud.

All the participants agreed that it was easy to use the screen reader for questions requiring a keyboard. Key screen-reader functionality included navigation commands and synthesized speech. And all agreed or strongly agreed that it was easy to type in short numerical answers on the computer keyboard.

The four participants agreed or strongly agreed that it was easy to understand the tables (row headings, column headings, and cells) using the system. It seems significant that both participants who used the blind mode strongly agreed, since access to tabular data is often a significant problem for individuals who are blind. Finally, the four participants strongly agreed or agreed that when their answer was wrong, the system helped them to understand why the answer was wrong. This is a positive indication of the value of this approach for learning.

Specific reactions to the two modes

When evaluating the low vision mode, S2 strongly agreed with statements about liking the capabilities for changing color schemes, magnifying the screen, having the test read aloud, and changing the rate at which speech is played. S1 neither agreed nor disagreed with these statements, except for the statement about liking the capability of having the test read aloud, to which he strongly agreed.

A key finding regarding the blind mode was the usability of the overlay sheets: Both individuals who used the TTT's plastic overlay sheets found them easy to switch; S3 strongly agreed with the statement and S4 agreed with the statement about the ease of switching. Ease in switching the overlay sheets is critical, since it enables students to function independently within a learning or assessment setting that uses a TTT. The students who used the blind mode were also asked to compare their preference for TTT relative to other access solutions.

S3 agreed or strongly agreed with statements beginning with "For understanding graphics, charts, tables, and math expression, I prefer the TTT system over" and ending with one of the following: "prerecorded audio alone," "raised-line graphics and prerecorded audio," and "raised-line graphics and a braille test booklet." Responses by S4 were "neither agree nor disagree," "agree," and "disagree," respectively. Thus, for these three questions, TTT was preferred over each stated alternative by at least one of the two individuals.

Regarding the statement, "For taking important math tests, I prefer the TTT over a human reader and a test booklet with braille and raised-line pictures," S3 indicated "disagree" and S4 indicated "neither agree nor disagree." This reaction suggests that the option that includes the use of a human reader (a relatively expensive solution) is fairly attractive. This result underscores, among other things, the diversity among individuals with visual impairments. It may also reflect the relatively strong preference for braille and human readers among some individuals with visual impairments, particularly those who are totally blind. TTT requires the ability to use audio but does not require the use of braille. Braille labels are provided as a convenience to individuals who use braille, but a person who relies on braille alone (that is, an individual who is deaf-blind) would need extra assistance (a hearing human assistant, for example) to use the system.

Two final questions were asked of all four participants. In response to the statement "Having used the system during this session, I think that I now know how to use the system well enough to use it for an important test," three of the four participants agreed or strongly agreed. And in response to the statement, "I enjoyed taking the test," the same three participants agreed or strongly agreed.

Strengths and weaknesses of ACED

Table 4 presents the participants' comments about the strengths of the system (features they liked) and its weaknesses (features they disliked). All the participants liked the audio capabilities, and those who used TTT (S3 and S4) liked the audio-tactile capabilities. Regarding areas for improvement, the participants who used the low vision mode (S1 and S2) found limitations in color modification and enlargement, and one participant (S4) who used the blind mode would have liked navigation and setup to have been easier.

Discussion and conclusions

All four participants found both modes of ACED to be a generally usable mathematics AfL system. The findings illustrate the value that some users with

Table 4
Strengths and weaknesses of various ACED features.

Issue	S1	S2	S3	S4
What features did you like the most?	Voice (speech) along with the on-screen text. Voice is better than others used.	Prerecorded audio and (synthesized) audio.	Audio-tactile interactivity, feedback, and confirmation. System and content are easy after some practice. Multimodal approach is helpful. Easy-to-repeat question, and voice is clear. Rephrasing of question is available. On-screen calculator. Booklet on holder.	Could press anywhere, and it would tell you what you were pressing. Tactile parts were helpful. The narrator was clear and easy to understand.
What features did you really not like or think should be fixed?	Wanted higher color-contrast options. The current color-contrast options are too close to each other.	The enlargement (magnification) was too much, too tiring. Liked the voice better.	(None)	Need an easier way to repeat parts of questions (instead of using up and down arrows). You should be able to press the circle button to hear just the section you are on. Setup should require less pressing of things.

visual impairments find in such features of a test system as speech output (synthesized and prerecorded) and interactive audio-tactile graphics. The diversity of accessibility features—such as prerecorded and synthesized speech and audio-tactile graphics—appeared to contribute to the overall positive response to the approach.

Limitations and future work

The certainty of the conclusions of the study is limited by the small number of participants. Future studies need to use large samples of students interacting with greater amounts of content. They may also focus on specific combinations of visual impairment and preferred access methods, such as these: a blind user or one with low vision who accesses print primarily with audio, a blind person who prefers braille, a blind user who prefers both large print and audio, a person with low vision who relies primarily on print, and so forth. Studies may also focus on students with other disabilities, such as those with learning disabilities and those who are deaf or hard of hearing.

Implications

That one computer-based AfL can be made accessible for and usable by students with visual impairments helps to confirm the feasibility of addressing accessibility for many more such systems. Such information may prove valuable to technologists who examine the potential use of computer technology for developing educational systems that are usable by diverse students, by administrators who are seeking to plan to use such resources, and by teachers who are looking for ways to improve students' learning. By illustrating how the accessibility of an AfL system may be addressed early in a design, the study suggested a procedure that may be adapted to other AfL systems and for a range of disabilities. The study has illuminated how such systems can be designed to serve both sighted students and students with visual impairments.

The study provides an example of how a single system can incorporate features that would make assessments, including AfLs, accessible to both sighted individuals and those with visual impairments. By making diverse accessibility features available in a single system, ACED has enabled the benefits of elaborative feedback and adaptive sequencing to become available to individuals who are blind or have low vision. As such, the project represents a step forward in the quest to ensure equity and access to learning materials for all individuals, regardless of their disabilities.

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