TECHNOLOGIES THAT FACILITATE THE STUDY OF ADVANCED MATHEMATICS BY STUDENTS WHO ARE BLIND: TEACHERS' PERSPECTIVES

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This research examined the perspectives of teachers of students with visual impairments (TVIs) regarding the use and effectiveness of electronic assistive technology (EAT) purported to assist students who are blind in advanced mathematics subjects. The data for this study were collected via an online survey distributed to a convenience sample of teachers with experience teaching or supporting students who are braille readers in advanced mathematics classes. Questions were designed to gain information regarding which of 35 tools presented in the instrument were used to aid students, how were they used and perceived effectiveness. Open-ended response areas provided space for addition of tools not already listed, as well as other feedback. A total of 82 surveys were analyzed. Results indicated that 20 of the 35 devices were used; of these, 13 were used regardless of specific subject, while different sets were used for different subjects and tasks. Participants recommended another seven high-tech devices in the open response question. Limitations of the study were the small sample size and possible survey fatigue. Implications for practitioners: This research provides a foundation for additional work on how to best equip teachers of students with visual impairments so they can support their students.

In the last 30 years the technology boom has produced an abundance of tools to assist with learning and teaching, including those useful to teachers of students with visual impairments (TVIs). However, facilitating the study of mathematics for students who are blind, specifically braille readers, requires that TVIs engage in the arduous process of sifting through a growing number of continuously evolving products. Often, itinerant TVIs may have only one such student in their entire careers, and will have very little time to tackle a trial-and-error process (Zhou, Parker, Smith, & Griffin-Shirley, 2011).

High-quality teaching incorporates tools to help students with and without vision to access and understand advanced mathematics to the best of their ability. For classroom teachers who have a student who is blind, the presence of technology in the classroom is not optional, but necessary. Yet, according to Pierce and Ball (2009), 24% of teachers agreed or strongly agreed with the following statement: *If I use more technology, I won't have time to cover the course*. With this sort of pre-existing paradigm, any enthusiasm a classroom teacher may have felt at the prospect of teaching a braille reader will be quickly extinguished.

Many mathematicians, such as Buteau, Marshall, Jarvis, and Lavicza (2010), now believe that being proficient in advanced mathematics has become synonymous with being proficient in corresponding technology. Technology can eliminate the tediousness of calculations, allowing students to focus more on conceptual understanding. Students who are blind must have technology that provides these same supports. Schweikhardt (2000) noted that requirements for the successful integration of students who are blind into regular education mathematics environments include notation simultaneously accessible by both people who are braille readers and those who are print readers. Numerous projects that focus on this aspect of learning—MathGenie and Lambda systems, for example—incorporate other technologies, such as MathML and MathType. Other various audio and speech capabilities projects are in development around the world (Karshmer, Gupta, & Pontelli, 2009). At this time, none of these projects have resulted in a single, streamlined solution.

Reed and Curtis (2011) conducted a study attempting to understand the issues teachers encountered when students with visual impairments transitioned to higher education. Difficulties identified were in students' abilities to access accommodations, getting accessible materials in time, and late arrival and poor quality of books transcribed into braille. In some cases, teachers indicated students who did not have enough training in using technology efficiently avoided its use altogether so as not to draw attention to themselves.

Smith, Kelley, Maushak, Griffin-Shirley, and Lan's (2009) Delphi study attempted to define a set of appropriate assistive technology competencies and corresponding levels of expertise for TVIs. After five rounds of deliberations, a list of 111 competencies emerged. Of those, 74 competencies were included in the Zhou, et al., (2011**)** study, which attempted to determine what level of expertise in each competency TVIs perceived as necessary to perform their jobs, and whether it aligned with what the expert panelists perceived as optimal in the Delphi study (Smith et al., 2009). Results indicated discrepancies in the priority ranking of some of the competencies between what panelists versus TVIs deemed important. Open-response items (Zhou et al., 2011) yielded insights from TVIs who said they just *cannot attend to every technology available* until a student actually needs it.

Purpose

The purpose of this study was to determine the current state—as perceived by TVIs—of electronic assistive technology (EAT) being used in advanced mathematics classes to support students who are blind, in an attempt to begin to uncover whether a mathematics toolkit for braille readers can be identified. The research questions addressed were:

1. Which devices are currently being used in secondary school advanced mathematics courses to support students who are blind?
2. Is there a core set of devices that is perceived as beneficial for supporting advanced mathematics students who are blind, regardless of specific subject?
3. Are there variations of the core set of devices, depending on the particular advanced mathematics subject being taught?
4. How effective are the tools listed in ensuring access and supporting learning by braille readers throughout typical lesson plan steps?
5. Are there gaps between technologies being used and teaching activities (i.e., lesson plan steps that are not supported, either overall or in specific subjects)?
6. What themes emerge from TVIs' recommendations of devices that were not listed or used in ways not indicated?

Ultimately, this research attempts to begin to uncover whether a mathematics for braille readers TVI *tool kit* can be developed.

Methodology

Participants and Procedure

The target population for this study was a sample of TVIs with experience in facilitating the study of advanced mathematics by students who are blind. Out of an estimated 6,700 certified TVIs (Mason, McNerney, Davidson, & McNear, 2000), only a small number would have worked with students who were exclusively braille readers and who had taken advanced mathematics. Furthermore, contacting that target while maintaining anonymity of participants was not feasible. As a result, a convenience sample was used.

Four sources—APH field-testers, *APH News* readers, state residential schools for students who are blind, and APH Ex Officio Trustees (appointed professionals in charge of administering Federal Quota accounts)—provided the convenience sample. Participants received the online survey instrument regarding their perceptions of use of EATs via e-mail or by going to the link indicated in the *APH News* announcement. Respondent criteria were TVIs with experience in facilitating the study of advanced mathematics by students who were braille readers. Advanced mathematics was defined as algebra and beyond. Potential participants were asked not to respond if they did not meet these criteria.

APH forwarded the link via e-mail to its field-testing volunteers and Ex Officio Trustees. Additionally, an announcement was placed in the January 2012 issue of the APH newsletter, with a link to the online survey. The president of the Council of Schools for the Blind (COSB) agreed to send the survey link to residential schools for the blind and ask that it be forwarded to their TVIs teaching advanced mathematics.

Instrumentation

The survey instrument to gather information in order to answer the research questions was developed using SurveyMonkey.com. The first seven items collected participants' descriptive information. In item 8, participants rated their perceived proficiency in integrating technology for the purpose of supporting braille readers with no vision in advanced mathematics courses, on a scale from zero to five where 5 would indicate very high perceived proficiency. Respondents were asked to rate their technological proficiency in six secondary school subjects; algebra, algebra 2, geometry, trigonometry, pre-calculus, and calculus. Items 9 through 11 had respondents determine the three subjects in which they had the highest technological proficiency. Using conditional branching (Alreck & Settle, 2004), answers to these questions were inserted into further questions about specific EAT usage in each identified course.

Instrumentation

The crux of the survey was a device matrix. The EAT list was generated during the literature review, but their appropriateness for this student population was unclear. Many tools were available for mathematics-related professionals who were blind or for individuals with limited vision. Two EAT expert TVIs in Austin, TX, one itinerant with over 25 years experience, and the other, a math classroom teacher at Texas School for the Blind and Visually Impaired, each reviewed this initial version of the survey. Their insight led to some changes in the EAT list included in the survey, and the addition of open-response space. Participants went down the list until reaching a device with which they had experience. They then consulted column headers to determine which step(s) of the lesson plan the device supported. Lesson plans steps were defined as:

- Preparation of lessons – the device was used by a faculty or staff member to prepare the mathematics lesson, notes, and/or materials for the lesson, before the lesson itself took place.
- Student lesson access – the device was used by the student during the lesson, on the actual day of the lesson, in order to access the notes or demonstration his or her peers were accessing visually.
- Teacher/student guided practice – the device was used by the student and classroom teacher or TVI, so they could simultaneously study, discuss, or work on mathematics problems.
- Student independent practice – the device was used by the student in or out of the classroom to work on problems independently.
- Student work submission – the device was used by the student or staff member to create a print document that could be read by the classroom teacher.

Finally, they rated the device on a 1- (lowest) to-5 (highest) scale for its effectiveness in supporting the student in each lesson plan step for that subject. If the teacher believed the EAT used or the ratings given depended on the subject, the TVI repeated the matrix for the next subject.

Data collected via the device matrix addressed the first five research questions. Criteria for *beneficial* were established through collaboration with two experts in the field, with the intent of identifying as many devices as possible for further research. EAT reported as being used by more than 50% of participating TVIs, or having a mean rating of ≥ 3 in any of the lesson plan steps, met *beneficial* criteria. Following the device matrix was the first open-response space for TVIs to list any other EAT they perceived as facilitating the study of a particular subject by students who were blind. A second space was provided for addition information participants deemed important regarding the integration of high-tech tools for educating students who are blind.

This instrument was approved by Texas Tech University's Institutional Review Board’s (IRB) for exempt review. Settings in the instrument’s web page prevented obtaining IP addresses and TVIs were notified that participation was voluntary and anonymous. A $50 Amazon.com gift card was offered as incentive. SurveyMonkey did not share survey results or participant contact information with researchers.

Data Analysis

The analysis of the interrelationship of subject, effectiveness of technology, and each step of the lesson plan was done through visual examination of the results. Cross-tabulation analysis was not performed because the purpose of the research was to be inclusive of all EAT, even those with very low relationships to the independent variables. This survey was a starting point, and each device identified warranted further examination. Microsoft's Excel™ program was used to sort data, create graphs and tables, and calculate means and standard deviations.

Results

A total of 157 surveys were returned, eighty-two surveys (52%) of were complete through the device matrix item. The data reported in this research are from the 82 completed surveys.

Descriptive Data

The population for the study was TVIs who had experience teaching and supporting braille readers in advanced mathematics courses, as listed in Table 1. Thirty-one of the 82 respondents, the highest percentage (38%), indicated over 10 years experience working with students who are blind in advanced mathematics, with 54 (66%) respondents selected 2011-2012 as their most recent year. Note that 60 (73%) of respondents listed their current positions as itinerant TVIs.

Table 1. Descriptive Data of Respondents (N = 82)

Descriptive Data	*n*	%
Age		
< 28	4	4.9
29–36	9	11.0
37–44	8	9.8
45–52	13	15.9
53–60	39	47.5
61–68	9	11.0
> 68	0	0.0
Geographic region		

Descriptive Data	*n*	%
Northeast	15	18.3
Midwest	27	32.9
South	27	32.9
West	13	15.9
Years experience[1]		
1–3	24	29.2
4–6	19	23.1
7–10	6	7.3
> 10	31	37.8
NA	2	2.4
Most recent year		
2011–2012	54	65.9

Descriptive Data		*n*	%
	2010–2011	7	8.5
	2009–2010	8	9.8
	2008–2009	5	6.1
	2007–2008	0	0.0
	2006–2007	3	3.7
	2005–2006	2	2.4
	2004–2005	2	2.4
	1998–2004	0	0.0
	Before 1997	1	1.2
Current position			
	teacher at a residential school for the blind	9	11.1
	itinerant TVI	60	73.1
	resource room or self-contained classroom teacher	8	9.8

Descriptive Data	*n*	%
regional education service center or school district	3	3.7
rehabilitation center	0	0.0
TVI and working in a supervisory or administrative role	0	0.0
independent consultant	0	0.0
Other	2	2.4
NA	1	1.2
Other		

Descriptive Data		*n*	%
Previous positions			
	teacher at a residential school for the blind	14	17.0
	itinerant TVI	66	80.5
	resource room or self-contained classroom teacher	18	22.0
	regional education service center or school district	9	11.1
	rehabilitation center	1	1.2
	independent consultant	5	6.1

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1. Total number of years of experience working with students who are blind in advanced mathematics courses.

Participants' Perceived Proficiency

As shown in Table 2, many participants indicated proficiency in more than one subject, and nine participants added *statistics* or *statistics and probability* to the *other* subject for an average rating of 2.11.

Table 2. Participants' Perceived Proficiency – Scale of 1 to 5 with 1 Being Lowest

Answer options	1	2	3	4	5	Average	*n*
Algebra 1	12	9	35	15	11	3.02	82
Algebra 2	15	15	21	18	6	2.80	75
Geometry	18	10	26	13	8	2.77	75
Trigonometry	28	10	13	7	4	2.18	62
Pre-calculus	31	10	17	3	3	2.02	64
Calculus	38	12	8	2	1	1.62	61
Other	4	1	3	1	0	2.11	9
Other (please specify)							4

Once participants determined the relative technological proficiency for the various subjects, they were asked in which subject they perceived themselves to be the most proficient in supporting a student who was blind in an advanced mathematics subject (Table 3). In order to minimize the effects of survey fatigue, participants would enter responses to the device matrix based on the subject in which they perceived themselves most proficient first. Teachers were then asked to determine in which subject they had the second highest technological proficiency or to indicate experience in only one subject. Finally, teachers were asked in which subject they had the third highest technological proficiency.

Table 3. Perceived Proficiencies

	Highest		Second Highest		Third Highest	
Subjects	*n*	%	*n*	%	*n*	%
Algebra 1	57	69.9%	16	20.5%	1	1.4%
Algebra 2	11	13.3%	34	41.0%	19	25.7%
Geometry	11	13.3%	19	22.9%	25	33.8%
Trigonometry	1	1.2%	2	2.4%	6	8.1%
Precalculus	2	2.4%	0	0.0%	3	4.1%
Calculus	0	0.0%	1	1.2%	1	1.4%
Other (please specify)	0	0.0%	0	0.0%	0	0.0%

Answers to Research Questions

Device Usage

In determining which of the 35 EAT was being used, the data were analyzed in two ways. First, each device received a score based on the total number of times the tool was selected for use in various subjects and lesson plan steps, regardless of the number of participants who selected it. According to this analysis, all of the devices presented were used by at least one teacher, in one subject, for one lesson plan step.

The second analysis counted how many participants said they used each device without regard to the number of subjects or lesson plan steps. Every single one of the 35 devices was used by at least nine teachers. That is, not a single device was used by less than nine teachers. Individual examination of the completed surveys revealed these nine participants entered a *1* in all of the Likert ratings for every part of the lesson plan in which they didn't enter a higher rating. It is possible that participants did not realize ratings should be left blank for unused EAT. Since some of the devices did rate higher than 1, it is impossible to eliminate entire surveys. It can be concluded that 20 devices—the number selected by at least 10 participants—were used by between 1 and 62 teachers.

Perceived as Beneficial

Research questions two through four involved perceptions of EAT as *beneficial*. That is, the device must either have been reported as being used by more than 50% of participating TVIs, or have a mean rating of 3 or more in any of the lesson plan steps. Question two focused on identification of a core set of EAT perceived as beneficial in supporting the study of advanced mathematics by students who are blind, regardless of specific subject. The 13 devices that met criteria are:

- Personal Computers (PCs)
- Scanner/Reader
- Electronic Refreshable Braille Notetakers (ERBN)
- MathFlash
- Talking Calculators
- Excel
- Talking Scientific Calculators (TSC)
- Audio Recording
- Duxbury's DBT WIN
- OCR Software
- Scientific Notebook
- Graph-It
- Accessible Graphing Calculator (AGC)

The third research question looked more intently at EAT use for specific subjects. In this case, more devices met the beneficial criteria based on number of participants who selected them. The results are shown in Table 4.

Table 4. Number of Participants Who Selected Devices by Subject

Device	Algebra 1 (*N* = 57	Algebra 2 (*N* = 11)	Geometry (*N* = 11)	Trigonometry (*N* = 1)	Precalculus (*N* = 2)
PC	41	8	10	1	2
ERBN	42	7	9	1	1
Audio Recording	19	4	5	0	1
Talking Calculator	35	7	10	0	1
Talking Scientific Calculator	38	9	6	0	2
AGC	22	5	6	0	2
OCR Software	15	2	2	0	0
Scanner/Reader	18	4	7	1	1
Nomad Pad/Tablet	5	2	2	0	0

Talking Tactile Tablet	5	2	2	0	0
Talking Tactile Pen	6	2	2	0	0
Tactile AudioGraphics TagPad	5	2	2	0	0
MathPlayer (Design Science)	5	2	2	0	0
MathSpeak	6	2	2	0	0
ReadHear	5	2	2	0	0
ClickHear	5	2	2	0	0
TRIANGLE	5	2	2	0	0
AudioMath	5	2	2	0	0
Graph-It	6	4	3	1	0
GRAPH	6	3	2	0	0
AsTeR	5	2	2	0	0
MathTalk with MathPad	5	2	2	0	0
MathTalk with Scientific Notebook	6	2	2	0	0
AudioCAD	5	2	2	0	0
AudioPIX	5	2	2	0	0
MegaMath	5	2	2	0	0
Duxbury's DBT WIN	33	6	8	1	2
IVEO	6	2	2	0	0
Math Program	7	2	3	0	0
Scientific Notebook	26	5	5	1	2
MathTalk	6	2	2	0	0
MathFlow	5	2	2	0	0
MathDaisy	5	2	2	0	0
MathFlash	9	2	3	0	0
Excel	11	2	5	0	0

Gaps in Supporting Tasks

Four devices met the criteria for beneficial in three out of the five lesson plan steps; the PC, ERBN, talking calculator, and TSC. More tools met the mean score criteria than the 50% participant criteria, and no lesson plan tasks were completely unsupported (see Table 5).

Table 5. Devices With Mean ≥ 3 in at Least One Lesson Plan Task

Preparation of materials	Student lesson plan access	Teacher/student-guided practice	Student independent practice	Student work submission
PC	PC	PC	ERBN	PC
Audio recording	ERBN	ERBN	Talking calculator	ERBN
Talking calculator	Audio recording	Talking calculator	TSC	Talking calculator
TSC	Talking calculator	TSC	AGC	TSC
AGC	TSC	AGC	Scanner/reader	AGC
OCR Software	AGC	DBT WIN	Graph-It	DBT WIN
Scanner/reader	Scanner/reader	Scientific Notebook	DBT WIN	Excel
Graph-It	DBT WIN	MathFlash		
DBT WIN	Scientific Notebook	Excel		
Scientific Notebook	Excel			
Excel				

Themes
Table 6 summarizes additional devices not included in the matrix that were recommended by participants in the open response question. Half of the 14 devices listed are low-tech. Open coding analysis of the 37 clauses provided as information deemed important is provided in Table 7. The table shows four major categories emerged; low-tech devices, teacher training, mathematics complexity, and high-tech (EAT) devices. All of the nine clauses regarding low-tech devices regard their benefits. Six clauses have to do with teacher training. Math characteristics and EAT each have 11 clauses related to them.

Discussion and Implications

The device matrix and open-ended questions were designed to determine which devices were being used, which were considered beneficial, in what subjects they were being used, and how and when they were being used. A large portion of the devices were used very infrequently. The number of braille readers in advanced mathematics courses is small. Therefore, the use of a device, even by one teacher, warrants further investigation of the tool's potential benefits. It is possible for one teacher working with one student to discover a technological solution beneficial to other educators working with similar students (Maneki, 2010).

Of those 20 devices identified as being used, a core set of thirteen met the criteria for *beneficial*, regardless of specific subject. Each of these devices is a candidate for inclusion in a TVI *tool kit* used to support braille readers in advanced mathematics. In addition, results indicate that this core set of beneficial tools varied depending on subject. In geometry, seven of the devices met the beneficial criteria, whereas in algebra only four devices did. Practical implications are that school districts or regions can maintain a core set, or sets, and make relevant devices available to students according to subject. Because blindness is considered a low-incidence disability and a small number of these students function at academic levels, it is feasible that school districts could anticipate in what year a student would take each advanced mathematics subject. A corresponding tool kit could then be prepared.

Table 6. Open-Ended Responses to Technologies

Device	n	High-Tech?
Software		
MathType	3	Y
MathTrax	1	Y
Notetakers		
Refreshable braille notetaker with display	1	Y
Perkins braillewriter	7	N
Embossers/thermal printers		
Tiger Embosser	3	Y
Picture In A Flash	4	Y
ViewPlus	1	Y
Tactile boards		
APH Graph Board	2	N
APH Draftsman	6	N
APH Magnetic Board	1	N
Other manipulatives		
Math Window® Braille Basic Math Kit	2	N
Geometric manipulatives	5	N
Other		
Abacus	2	N
Digital cameras	3	Y

Table 7. Open-Response Categories and Concepts

Major categories	Associated concepts
Low-tech devices	Simpler, most effective, concept development
Teacher training	Unfamiliar, need training, training unavailable
Math characteristics	Need many tools, need immediate tactile representation, need real-time transcription, students not interested in math
High-tech devices	Inadequate graphing calculators, unavailable technology, too expensive, glitches.

Breaking down the typical lesson plan into component parts enables understanding of how EAT were used and by whom. Results displayed in Table 7 indicate preparation of materials, which entails converting print to braille or Nemeth, is perceived by TVIs as supported by 11 devices. As the tasks incorporate more and more back translation and student involvement, fewer EAT meet the beneficial criteria. Student independent practice and submission of work are perceived by TVIs as supported by the fewest EAT with seven each. One participant commented, *The general problem which applies to all the math areas is that there isn't a Nemeth back translator so students can write their math in Nemeth braille and translate it back to print*. Translation between Nemeth and print continues to hinder many parts of the learning process. This finding was supported by the open response answers and reflects the shortage of technology that allows for real time back translation from braille and Nemeth into print (Karshmer, et al., 2009).

It is interesting to note that despite the high-tech boom, all open-response clauses regarding low-tech devices are positive, whereas all clauses within the teacher and EAT categories are negative. Three TVIs indicated that they are open to training and would like to integrate more EAT. In some cases, devices and/or training are not available due to expense, and school districts cannot keep up with what may be the latest devices (Zhou et al., 2011). The possibility that the perception of the time necessary to get training is inaccurate must be considered. Rapid evolution of technology in general may lead TVIs to resist integrating EAT because they assume there are many more relevant tools to sift through than there actually are. This study shows that the devices identified as beneficial specifically for braille readers in advanced mathematics classes were all developed over five years ago, and most are at least familiar to TVIs.

Unlike other subjects, such as history and english where topics grow and evolve with time, the topics in advanced mathematics do not change. Therefore, one possible solution is to develop a tool kit that integrates both high- and low-tech devices along with a manual that describes when and how to use each one. They may not always be the most up-to-date, but the kit and manual would provide a single source of information on a limited number of tools and how to use them for each topic.

Limitations and Recommendations for Future Research

Several limitations in this study should be considered when interpreting the findings. The list of devices created for the data-collection instrument was derived from the review of literature plus input from two VI professionals and may not be comprehensive. The matrix consisted of a long list of devices, potentially leading to order bias through routine answering strategies or respondent fatigue (Alreck & Settle, 2004). While the instrument uses objective measures, there is a degree of participant interpretation of the meaning of questions.

With regard to participants, the sample size was small and respondents self-selected. It is possible that TVIs with more expertise using EAT did not participate. In addition, the higher level subjects had extremely low response rates.

Additional in-depth research to identify newer EAT and detailed information on exactly who uses it, when, how, and for what purpose is necessary to integrate it into each lesson. Results of this research should lead to the development of user-friendly, subject-specific manuals for TVIs, classroom teachers, and students. TVIs identified as working in advanced mathematics with students who are blind may be equipped with a prototype EAT tool kit and a manual. Ideally, training on each device would be provided to all key persons, and qualitative data would be collected regarding practical applications and effectiveness.

At this time, there is no multipurpose device or system that translates print to braille and Nemeth (or Nemeth into print), and allows for simultaneous visual and tactile viewing, or mathematical manipulation. It is critical that research into development of electronic assistive technology designed for supporting braille readers in advanced mathematics continues. These study results provide a starting point for the development of a plan ensuring students who are blind obtain the maximum benefits from our high-tech world.

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