Using Accessible Math Textbooks with Students Who have Learning Disabilities

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ABSTRACT
Math is a subject that most students in K-12 participate in every school day. This includes students with learning disabilities as they are equally accountable to meeting general math curriculum requirements. Project SMART provided digital versions of math textbooks modified to include MathML for use by eighth grade students with various learning disabilities. A goal of Project SMART was to determine whether these accessible digital textbooks improved student test performance as compared to control groups using the same texts in print format with a traditional oral accommodation. The study also examined the extent to which using accessible math impacted student perceptions about math abilities. Students and most teachers found the accessible digital textbooks preferable to the print versions. This was generally reflected in higher test scores as well as consistently positive responses from qualitative measures obtained from ongoing student and teacher surveys.

Categories and Subject Descriptors
K.4.2 [**Computers and Society**]: Social Issues – *Assistive technologies for persons with disabilities*.
K.3.1 [**Computers and Education**]: *Computer-assisted instruction (CAI)*.

General Terms: Human Factors

Keywords: Accessibility, MathML, Print Disabilities, Math Disabilities, Visual Impairments, Learning Disabilities, DAISY.

1. INTRODUCTION
It has been known for a long time that computer support for reading is helpful to students with many different types of learning disabilities (see Section 2). Prior to the SMART study, no one had attempted to see if the same is true for reading mathematical content on a computer. Given that most K-12 students take a mathematics class every day, this poses a serious gap in our knowledge base about the usefulness of electronic versions of textbooks and supplemental materials used for teaching math.

Students with disabilities tend to perform well behind their peers without disabilities in math achievement. While the reasons for this are not fully known, research has shown that students with learning disabilities tend to lack the self-verbalization skills needed as the first step toward understanding the meaning of math expressions. However, since many of the common assistive technology reading applications used over the last decade have been unable to render math expressions aurally, the standard accommodation provided in the classroom is for the teacher or other school personnel to act as a human reader.

While the provision of a human reader is often regarded as providing a basic level of access to the general curriculum, federal law such as Section 504 of the Rehabilitation Act and Title II of the Americans with Disabilities Act (ADA) may require the provision of technology supports for reading when they are available. In the case of postsecondary textbook access for blind students, the U.S. Department of Education Office for Civil Rights has ruled that simply providing ad hoc access to textbooks through the use of assigned staff readers is not an acceptable practice when the amount and complexity of content and immediacy heavily favors other alternative methods [1]. At issue is not whether a student with a disability is merely provided access, but the issue is rather the extent to which the mode that the content is presented in is actually as effective as that provided to others.

Over the last decade, the provision of accessible textbooks has seen a shift from "books on tape" to electronic texts for use with a computer as one of the most effective techniques for providing access to textbook content. This has generally not been true for higher level mathematics content, however, but the advent of Mathematical Markup Language (MathML), and the accessibility protocols to support it, has now made this possible. Now that this capability has been firmly established, the opportunity to study the effectiveness of computer support for reading math is available.

This paper reports results from the Project SMART (Supported Math Accessibility Reading Tool) study. This study was conducted by the University of Kentucky with 48 eighth grade students learning math using Pearson's *Connected Mathematics 2* middle school math curriculum. In particular, this project attempted to measure student outcomes associated with providing accessible math content in the classroom by using digital textbooks created according to the National Instructional Materials Accessibility Standard (NIMAS) [3] combined with the DAISY [21] MathML modular extension.

The results of this study revealed that providing mathematics instructional content in this format did indeed have a positive impact on student performance. Section 4 of this paper discusses both the quantitative results of the study along with qualitative results from surveys of participating students and teachers. Both showed positive results for books with the greatest amounts of mathematical expressions, but were more mixed when the number of expressions were small relative to the amount of text.

2. Previous Work

Previous studies have focused on either electronic supports for reading literary materials with no mathematical content or have focused on comprehension of isolated mathematical expressions. Project SMART examined a standard textbook modified so that both the text and the math were fully accessible.

Previous research has shown that reading practice is essential to improved reading proficiency and that software that provides text-to-speech (TTS) provides such an opportunity [13, 24]. Poor readers have difficulty in many subjects because of their inability to acquire knowledge from reading standard textbooks [14, 15]. Mathematics is no exception: Light and DeFries found that more than 60% of students with learning disabilities exhibit significant disabilities in mathematics [12]. Research has also shown that students with language deficits react to math problems on the page as signals to do something, rather than as meaningful sentences that need to be read for understanding [6]. Computer-based readers have also been shown to improve reading comprehension of literary materials by dyslexic students [4]. Other studies have shown that as severity of a learning disability increases, speech synthesis systems enhance reading comprehension as less time has to be devoted to struggling with decoding of words [11, 19]. Computer software that provides synchronized visual and auditory presentation of text appears to be a promising aide to people who have poor reading skills [5]. Synchronized highlighting of text is now common in Assistive Technology (AT) designed for students with LD (e.g., Read&Write Gold [23], Kurzweil 3000 [10]). However, synchronized highlighting of mathematical expressions is still rare in AT.

The development of computer generated math speech began with ASTER [18], a system by Raman that reads LaTeX documents. ASTER uses prosodic cues (pauses plus changes to pitch, rate, volume, and voice) among other parameters to speak. Raman did not do experiments to test the efficacy of ASTER. Stevens et. al., [22] developed a DOS-based system called MathTalk in the mid 1990s. Experiments they performed using 24 sighted users showed that prosodic cues increased the success rate for recognizing both the structure and content of the expression. While it also reportedly lowered frustration rates of users, error rates were still unacceptably high—around 20%. Karshmer et. al., [2, 8] also did experiments involving sighted readers and listeners. Among their conclusions was that prosody was *not* effective for human speakers; tests were not done with computerized speech. The resulting software, MathGenie [9] does not use prosody.

All of the software projects mentioned above were self-contained systems. Soiffer took a different approach with MathPlayer [20]. MathPlayer is designed to work within widely used software and in conjunction with the user's AT. MathPlayer allows for some enlargement and visual highlighting during speech. MathPlayer's speech can use prosody if the AT can take advantage of it. Unlike the other systems, MathPlayer's speech style is not built in. It currently supports both SimpleSpeak, a semi-natural speech style, and MathSpeak [7], a speech style based on Nemeth Code [16]. A modified version of SimpleSpeak was used for Project SMART.

A verbal rendering of an audio expression is a linearization of inherently non-linear notation. It does not allow for the same degree of freedom to "browse" the expression as does the visual representation. Many of the systems mentioned here include methods to interact with the rendering to gain back some of the inherent two-dimensional structure and, therefore, facilitate grasp of the expression's structure and content.

There are many possible ways of navigating through a mathematical expression. ASTER presents a tree view of the expression that requires users to have a mental model of the tree that underlies the expression. This approach means that only a few motion commands are necessary such as "move to parent," "move to first child," and "move to next sibling." Most of the systems mentioned present some similar notion of an expression tree, allowing tree-based navigation and elision of detail.

MathTalk took a more visual approach. It developed a list of eight actions (current, next, into, level, etc.) and 9 targets (expressions, term, super, numerator, etc.), and movement was based on two key combinations of these action-target pairs (e.g., "nt" meant move to the next term). Use of the "current" command spoke the current level, "abstracting away" expressions such as a fraction contained in the current level (that is, instead of reading the fraction itself, it would simply say "fraction").

Although navigation is supported in many of the systems mentioned in the previous section, it appears that only Stevens [22] conducted experiments to see if it was useful. MathTalk explored the use of non-vocal output such as musical tones to help blind users understand the structure of an expression. Stevens reported a 73% success rate at identifying structure using musical tones and felt that redesign of some of the math-to-music mappings might eliminate some of the common errors.

Karshmer, et. al., [2, 8] explored how people remember mathematical expressions. Their experiments compared content, structure, and overviews, and reading order. They concluded that initial elision of content created difficulties, but that being able to review structures and "bookmark" them for easy re-examination was useful. They did not run tests on the software (MathGenie) they eventually produced.

3. Project SMART Design

3.1 The Students

The SMART study was conducted over a period of two years, with student participation divided into three stages. Stage 1 was an initial pilot phase conducted as a paired study during the spring 2008 semester with control and intervention students at Conkwright and Clark Middle Schools in Clark County, Kentucky. Stages 2 and 3 were paired study periods in which the control and intervention groups changed places during the fall 2008 and spring 2009 semesters at Shelby East Middle School in Shelby County, Kentucky. Although the aforementioned Clark Middle School also participated during the final two stages of the study, the number of students in this school was too small to include in the results presented here.

A combined total of 48 different students participated in Project SMART over the three study phases at the three participating schools. Students were randomly assigned to either the control or intervention group. Participants in this study were all eighth grade students with some form of print disability.

Figure 1: Two student participants in Project SMART

Primarily these were students with learning disabilities, but also included were students with mild cognitive disabilities, students with "other health impairments" such as Attention Deficit Hyperactivity Disorder, and students with other disabilities who had an Individual Educational Program (IEP) requiring a reading accommodation. The study was approved by an IRB and all the teachers, students, and parents provided their consent to be part of the study.

3.2 The Technology

The core technology approach of Project SMART was to deliver 8th grade mathematics content in an accessible digital format that could be read by students with print disabilities by using their standard AT. In order to make math content accessible, this study focused on using electronic content represented as XHTML+MathML. MathML captures the structure of the expression, not just the visual layout. MathML was designed to be accessible and is used by DAISY and NIMAS[1].

One of the goals of Project SMART from a technology perspective was to take advantage of digital math content without having to train students how to use a totally new assistive technology. The idea was that students would be best served by utilizing the same text reader technology they commonly used, rather than using an unfamiliar separate application that could only be used with math content. Since Read & Write Gold (RWG) from Texthelp, Inc., had been adopted by a majority of school districts in Kentucky as the standard text-reading assistive technology for students with non-visual print disabilities, using this application was the obvious choice for this study. RWG software interfaces with MathPlayer to provide a textual string to speak for the math and to highlight what is being spoken. This makes the way that the math is read much like the way RWG reads text.

The students in the two districts in the study used the *Connected Mathematics Program 2* by Pearson Education, Inc. Pearson converted the book from a PDF file into an XML file format in compliance with federal NIMAS provisions. The point of this process was for the publisher to prepare an electronic file just as they would for source files now commonly being prepared in compliance with NIMAS for submission to the National Instructional Materials Access Center (NIMAC). Additional work was needed to encode the math as MathML instead of as images. The resulting NIMAS+MathML file was then run through the CAST NIMAS Conversion Tool—a freely available application that was modified early in the project to work with MathML content in NIMAS XML source files. The output of this process generated a set of XHTML+MathML files, complete with all of the illustrations in associated image file formats. These collections of files were then copied onto CD-ROMs (one CD per textbook unit) which were then used by the intervention students in Project SMART.

The participating students were then assigned laptop PCs in math class and provided with individual ear bud headphones. Each laptop was running Windows XP Service Pack 2 and Internet Explorer 6. A development version of the MathPlayer add-on for Internet Explorer was loaded onto each laptop. Students used Read & Write Gold v8.1 Mobile as their assistive technology.

3.3 The Textbook

Pearson's *Connected Mathematics 2* Program curriculum was initially developed as an outcome of the Connected Mathematics Project led by Michigan State University with funding from the National Science Foundation. The entire 3-year series for grades 6-8 includes 24 units, equally spaced as a series of 8 units per each school year. Each unit is a separate booklet.

Although a total of seven unit booklets were converted as part of Project SMART, only four of these units were actually used by enough students for a sufficient period of time to include in the analysis of pre/post test scores. These four units are described in Table 1.

Through an inadvertent error in one of the publisher's conversion processes, *Looking for Pythagoras* was improperly formatted and all of the MathML content was stripped from the student CDs. So, although all of the literary text in this title was accessible to students via RWG, the students only heard and saw stray numbers and letters which were passed through in the conversion process.

As is further described in the next section, each unit booklet included varying amounts of math expressions with a range of complexity. Some titles also included much more graphical content than others, such as diagrams, graphs and geometric objects, though Project SMART was not designed to consider aspects of graphical information accessibility. The graphical content was tagged with minimal alternative text (e.g., "table" or "line graph") that provided only minimal information to the students. The main thrust of Project SMART was measuring the benefit of accessible mathematical

Table 1: *Connected Math* units used

Unit Title	Principal Objective
Say it with Symbols	Understanding mathematical symbols used in algebra
Looking for Pythagoras	Understanding the Pythagorean Theorem
Filling & Wrapping	Understanding area and volume measurement
Samples and Populations	Understanding data collection and statistical analysis

[1] At this time, MathML is optional in NIMAS. However, an amendment to NIMAS is moving through the regulatory process that mandates the use of MathML for math[17].

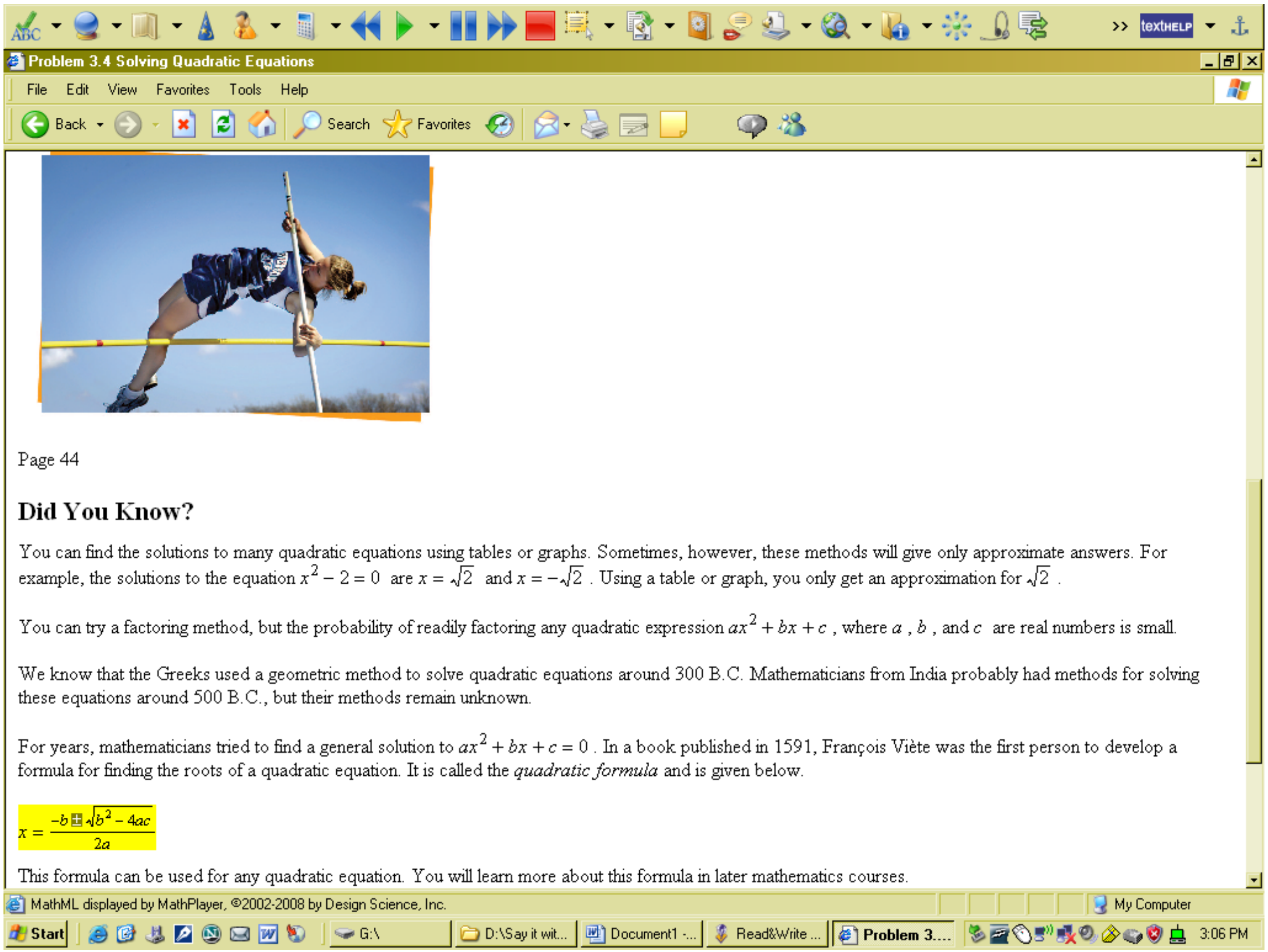

Figure 2: Read & Write Gold tool bar & sample page from *Say it with Symbols* by Pearson Education

notation rendered via MathML, so no attempt was made to improve the accessibility of the graphics.

4. The Results

The research agenda for Project SMART centered on three primary questions:

1. Does the MathPlayer technology coupled with text reader AT result in accurate rendering of math content sufficient to meet the access needs of students with print disabilities?
2. Does the provision of accessible math in a digital environment improve students' math performance?
3. Does the provision of accessible math in a digital environment affect student perception about their individual capabilities to use and understand math concepts?

To answer these questions, both qualitative and quantitative data was collected during each of the three stages. For qualitative purposes, surveys were designed pertaining to each of the research questions. These surveys were then conducted individually with students and teachers at the midpoint and end of each of the three semesters. Quantitative data was collected thru pre and post tests administered on each of the math units to students in both control and intervention groups. Overall, SMART findings showed that all three questions were answered in the affirmative. A detailed discussion of results for each question is included below.

4.1 Did the AT meet student's needs?

In Project SMART, one fundamental question was whether students with print disabilities would find speech access to mathematics content sufficiently accurate to meet their access needs. This question was qualitative in nature, and input was gathered from surveys of teachers, students, and the Project SMART math expert from the University of Kentucky. Analysis and aggregation of survey responses concluded that math content was being spoken accurately and that with some enhancements the rendering of math expressions through synthetic speech sufficiently met the access needs of students with non-visual print disabilities.

The adjustments required were in MathPlayer's speech rules to allow pronunciations which were more tailored to the needs of the Project SMART students who were all sighted, as opposed to the original settings which were designed for students who are blind. One very useful feature of using MathML is that the way mathematical information is spoken by speech technologies can be modified globally by changing the speech rules in the software. Thus, one can choose from a number of possible ways to verbalize a math expression. The flexibility here is very wide. For instance, the speech rules could be set to say either *minus*, *subtract*, *take away*, or some other appropriate phrase when a minus sign is encountered without having to modify the content itself. The software can also decide how much information about the expression is verbalized.

For students who are blind, it is essential to indicate the start/end of some notations. For example, it is important to distinguish between $x^n + 1$ and x^{n+1}, but these extra words are not needed and may even be confusing to a student who is sighted.

In Project SMART, the study began with an off-the-shelf version of MathPlayer, which included a standard set of speech rules designed with a blind user in mind. Teachers and students alike found some aspects of these rules to be bothersome, because so much of the expression was being verbalized. Since all of the students in the study were sighted, both teachers and students found the extra speech cues—like announcing a capital letter, or announcing the beginning and ending of a fraction—to be distracting to sighted students who primarily had learning and attention disorders.

For the study's second year, the project worked with Design Science to utilize a new version of MathPlayer then in development which provided the ability to customize speech rules. With input from teachers and the project math consultant, these rules were modified to more closely match the manner in which teachers typically verbalized expressions when writing them on the board or reading them to the class from the textbook. After changing to the new speech rules in the second year more students indicated on surveys that the computer read the expressions and numbers in a way that "sounds right."

4.2 Is Performance Improved?

Project SMART was designed to look at both quantitative and qualitative measures of potential positive impact on students' math learning. One of the project's quantitative measures was to track student performance on unit tests. The study compared pre and post unit test scores for students who were using the digital versions, and compared those scores with pre and post unit test scores for control students who were using the standard print textbooks. For the control group, school staff assisted the students with reading accommodation support upon request. Although some variation was noted by unit title, test score analysis revealed that student performance improved in most instances when complex math materials were delivered using MathML.

Table 2 shows the percentage change in test scores relative to the control group. The percentages in the "Difference of Intervention vs. Control" columns represent the difference in each group's average scores from pre-test to post-test. For instance, the +14% improvement for the intervention students shown in the *Say It with Symbols* row for CW-S08 is the difference between the average of 19% improvement in scores from pre to post on this unit for intervention students (N=6) and the average of 5% improvement in scores for the control students (N=6). The boxes with no data (–) means the unit listed was not being covered during that particular semester.

The small number of students, variations in the amount of time they spent on the material while using their computer, and variation between groups preclude a substantive statistical analysis of the numbers. Nonetheless, as the table shows, students using the digital versions containing MathML outperformed control students using standard print textbooks on the majority of unit tests administered over the duration of the study. One intriguing aspect of this data is that the title containing the most algebra and the most MathML expressions (*Say It With Symbols*) exhibited the most consistent improvement in pre/post test scores for intervention students using the digital version in comparison to control students using the print version. This increased performance was found across all study phases and at all study locations. On the other hand, the title containing very little MathML and very low notational complexity (*Samples and Populations*) showed mixed results. Although the reason for this was unclear, it may be the fact that this title included a substantial amount of inaccessible tables, charts and other graphical illustrations but very little notation. The negative results for *Looking for Pythagoras* are possibly due to the error in the conversion process, which may have ended up confusing the students.

4.3 How is perception of abilities affected?

On Project SMART surveys, the vast majority of students (96%) responded that they preferred using accessible digital versions of math textbooks instead of the paper copies. Student perceptions of individual capabilities were also positively affected as seen in survey responses where students reportedly thought they had done better on math tests and made better grades as a result of using their computers to access math content. Various teachers remarked on surveys that having math content in a form that can be read by assistive technology eliminated barriers in decoding so students could focus more on content and get on to a higher level of application and reasoning. Furthermore, multiple teachers commented that having accessible digital math content enabled greater learning independence by students with print disabilities by providing individual opportunities for re-reading and preview/review of classroom material. It was also reported as allowing teachers to spend less time helping students read the material, thus enabling them to devote more of their time to classroom instruction.

A few other highlights of student and teacher responses to qualitative survey questions about using AT for accessing the curriculum are included below:

- 90% of the teachers reported that the computer read math to the students better than the students could read it by themselves.
- 96% of the students surveyed preferred reading math on computer instead of on paper.
- 100% of teachers reported that the way the words and symbols light up and read out loud at the same time helped students read their math; while 79% of students said the same thing.
- 80% of students reported that when they have their math text on computer it is easier for them to read their math materials.
- 74% of students reported that reading their math text on computer made it easier to complete their math problems.
- 69% of students reported that reading math on computer improved their understanding of math
- 60% of students reported that reading their math textbook on the computer helped them do better on math tests, even though the tests themselves were not accessible.

Table 2: Performance change relative to controls

Book Title	Notational Complexity	MathML Density[2]	Difference Intervention vs. Control[3]								
				CW-S08		CK-S08		SE-F08		SE-S09	
				N	change	N	change	N	change	N	change
Say it With Symbols	High	10.95	**Difference**		**+14%**		**+16%**		**+8%**	–	—
			Intervention	6	19%	3	23%	13	32%		
			Control	6	5%	3	7%	8	24%		
Filling & Wrapping	Low	0.86	**Difference**		**+16%**	–	—	–	—	–	—
			Intervention	6	25%						
			Control	6	9%						
Samples and Populations	Very Low	0.35	**Difference**		**-3%**		**+10%**	–	—		**-5%**
			Intervention	5	9%	3	9%			8	22%
			Control	5	12%	3	1%			13	27%
Looking for Pythagoras	Medium	0.00[4]	**Difference**	–	—	–	—	–	—		**-22%**
			Intervention							8	9%
			Control							13	31%

4.3.1 Student Comments
A few of the open ended comments from students are below:

- "Can't concentrate when reading it by myself and computer helps me to concentrate"
- "Helps me to go over and over it until it finally gets in my head"
- "Lot easier to do the problems and get through it a lot quicker"
- "When I read it I think of something different but the computer shows me how to read it right"
- "When I am doing math with parenthesis, it shows me how to do the math problems and equations"
- "Now I can do it myself"

4.3.2 Teacher Comments
Overall, teachers were supportive of students using digital math content. A few of the benefits which teachers mentioned are below:

- "I like that the students are independent–saves teacher time for more important interaction than just reading"
- "Less embarrassing–they don't have to feel bad about not being able to read at same pace as other students"
- "Students get exposure to right way to say things–it's consistent every time"
- "Their listening vocabulary is higher than their reading level"
- "Hearing it read correctly so students don't get caught up in decoding"
- "When adults can't always be there the computer is better than student being bogged down and waiting."

As with any group of teachers, however, there will be varying degrees of agreement on incorporating new technology in a classroom setting. For instance, some teachers expressed concern that students using a computer in a regular classroom environment was disruptive and had the potential of taking attention away from his/her class instruction. Some examples of concerns cited by teachers were as follows:

- "Sometimes students miss out on what the teacher is saying"
- "Even if it's reading, I don't necessarily know if they are understanding it"
- "Computer can't explain it like the teacher can"
- "Occasions where human tone of voice may be better to help students understand"

5. Limitations of the Study
Although results from Project SMART provide strong evidence that the provision of accessible math can positively impact student learning, it was not possible to show statistical significance from an analysis of student scores gathered as part of this project. While it was hoped that many more students would be available for participation in the project, various unanticipated factors ultimately limited the number of student subjects. The use of only unit tests but no standardized assessment of math performance further restricted the ability to draw conclusions at generally recognized confidence levels. Nonetheless, the totality of student outcomes—consistent improvements in student performance when using high-density MathML titles and substantive qualitative evidence—provides important and encouraging data on the use of accessible mathematics in instructional content.

Education research conducted in a real learning environment may yield a more accurate assessment of an intervention's capability to positively impact student performance, but it also brings along significant hurdles. Issues such as classroom distractions, schedule disruptions, technical difficulties, as well as factors outside the school all complicate data gathering and study integrity. Project

[2] MathML density is the average number of MathML expressions per instructional page (excludes glossary, index, preface, etc.).

[3] CW-S08 is Conkwright Middle School, Spring 2008 semester; CK-S08 is Clark Middle School, Spring 2008 semester; SE-F08 is Shelby East Middle School, Fall 2008 semester; SE-S09 is Shelby East Middle School, Spring 2009 semester.

[4] As noted in the text, MathML for this booklet was inadvertently omitted from the copies given to the students.

SMART was not immune to these issues. A few of the most notable problems included the following:

- Schedule disruptions due to snow days were common, including numerous successive days out due to a massive ice storm in January of 2009. Additionally, numerous school-wide events and statewide testing interrupted the study timeline.
- Technology issues tended to cause continuing study delays. Due to the configuration of school information technology infrastructure, student laptops had to be connected to the network for them to work properly, but often the student laptops proved to be inconsistent in getting or staying connected to the schools' wireless network which caused unpredictable results, often frustrating students and teachers. Other problems included issues with laptop batteries not being charged in time for class, and automatic software updating processes which on occasion would render laptops unusable when needed.
- Classroom instruction sometimes afforded little time for student interaction with textbook content. Some days would see no use of textbook content, and even when the textbook was being used, laptop startup times and getting the book loaded limited the amount of opportunity for utilization of digital content in the classroom. Some teachers regarded student use of laptops in the regular classroom as disruptive to the instructional environment and preferred that the technology be used during study time outside of the classroom. Further, some students indicated that using digital content in general education settings made them appear different from other students and this was a disincentive for them to use the technology at times. It was found though that this negative student perception of use could be ameliorated by how positively the teacher introduced it to all students.

Some of these limitations will diminish as digital textbooks and computers become commonly used in all classes and by all students, not just the few that need AT support.

6. Conclusions & Future Work

Section 4 shows positive results from this first-ever study on accessible digital math textbooks in the classroom: students and teachers liked using the digital versions of their textbooks; students' scores tended to be higher using the digital textbooks; and students felt greater independence ("Now I can do it myself"). These positive results occurred despite the fact that only the textbooks were accessible. In practice the frequency and amount of time devoted to use of textbook content in the classroom depended upon the unit topic and the instructional style of the teacher. During some class periods the textbook was used sparingly. Future studies should make the entire math curriculum (supplementary materials, content created by teachers, homework sheets, and unit tests) accessible electronically to better measure the importance of accessible math. It was noted by students as well as teachers during interviews that the unit assessments were not available electronically.

Section 5 pointed out a number of the problems that arose from the classroom environment such as IT issues; batteries not being charged; and sporadic outages that meant laptops needed to be rebooted during usage of the text. Hopefully, these issues will fade as computers become more common in the classroom.

The study did identify some areas for further investigation and or development. One improvement involved navigating to specific pages. At times, students needed to refer to their printed textbooks because the teacher referenced the lesson by page number. Although page numbers were part of the digital textbook, the books were divided into sections, not pages, and this made finding a given page number more difficult. A fix to the CAST converter has already been made to allow direct access by page number.

A more difficult problem to fix is adding flexibility so that students can selectively read a discrete part of a math expression. Expressions can be conceptually complicated and rereading parts of them such as the numerator of a fraction can aid in their understanding. MathPlayer currently lacks the ability to selectively navigate equations when used with RWG, although this navigation is supported by MathPlayer with some other AT. Section 2 discussed the work of others with navigation of math, but testing to see if that navigation is helpful has been very limited. In informal experiments with untrained people using an experimental version of MathPlayer, people were not able to discover navigation except via arrow keys (which moved by "word"). Finding a navigation scheme that is simple to understand for people with various disabilities remains a challenge. However, for students with LD, a simpler solution is to read from the point of a click onward or just read a selection and this fits well with how AT such as RWG works.

A much harder problem is making the math assessments accessible. A fully accessible assessment requires *both* accessible reading and accessible writing of math. An accessible math editor (one that speaks and highlights) is not available at this time.

Project SMART was designed to evaluate the effect of accessible math expressions. It did not look at making tables, charts, plots, graphs, and other types of images more accessible. In the texts used, the image density[5] ranged from a low around 0.3 to high around 1.9. To our knowledge, no studies have been done that show how effective it would be to make the images in textbooks accessible for students with LD.

No 8th grade students with limited vision or who were blind were available in the participating schools at the time of the study. Therefore, it is not known how effective accessible textbooks and supplementary materials would be for this population although it seems likely they would be very helpful.

Project SMART represents an important first step in gathering scientifically-based research data on the use of accessible digital mathematics in the classroom. Many of the Project SMART personnel are part of a new multi-site national research center: the Mathematics eText Research Center (MeTRC). MeTRC is based at the University of Oregon's Center for Advanced Technology in Education (CATE). This center is supported by funding from the U.S. Department of Education (CFDA No. 84.327H). The MeTRC study will go much further than Project SMART by implementing accessible math content for the entire math curriculum, including supplementary and teacher generated math materials. Doing so will provide the capability to study the myriad of factors that influence accessible math instruction in a live learning environment. It is hoped that by making all mathematical materials accessible to students everywhere (classroom, resource room, home), better methods of

[5] Image density is similar to MathML density. It is the average number of instructional images (charts, plots, graphs) per instructional page (excludes glossary, index, preface, etc.). Pictures, such as the one in Figure 2, are not included in image density calculations.

leveling the playing ground in mathematics education will be discovered.

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