

Research Report
ETS RR-17-13

Expanding Audio Access to Mathematics Expressions by Students With Visual Impairments via MathML

Lois Frankel

Beth Brownstein

Neil Soiffer

April 2017

ETS Research Report Series

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RESEARCH REPORT

Expanding Audio Access to Mathematics Expressions by Students With Visual Impairments via MathML

Lois Frankel,¹ Beth Brownstein,¹ & Neil Soiffer²

¹ Educational Testing Service, Princeton, NJ

² Design Science, Long Beach, CA

This report describes the pilot conducted in the final phase of a project, Expanding Audio Access to Mathematics Expressions by Students With Visual Impairments via MathML, to provide easy-to-use tools for authoring and rendering secondary-school algebra-level math expressions in synthesized speech that is useful for students with blindness or low vision. The pilot evaluated the authoring and speech-rendition tools, including interactive navigation. Teachers participated in the portion of the study that evaluated the authoring tools. Secondary school students with blindness or low vision participated in the portion that evaluated the speech-rendition and navigation tools, comparing those tools to each student's usual method (braille or print) for working with math. The teachers received an interactive authoring tutorial and the students received an interactive navigation tutorial before using the tools studied. Prior to the pilot, feedback studies on authoring and navigation gathered information that was used to fine-tune the tutorials and the functionalities being evaluated. In the pilot we attempted to simulate a likely use-case for each group. In the students' case, the tools for reading and navigating spoken mathematics were compared directly with the methods each student typically used for reading math (braille or print in a size appropriate for the student). Teachers and content providers were instructed to author math expressions that matched those used in the pilot instruments given to the students. The studies showed that the authoring tools were easy for teachers to use as intended and that little observable difference existed between students' success in answering math and math-parsing questions when using the spoken math tools and their success in answering parallel questions posed in braille or print of appropriate size. Please see Appendix E for information on obtaining a version of this report that is fully accessible using the tools described.

Keywords Math; accessibility; blindness; visual impairment; text-to-speech; MathML; prosody; algebra; STEM; ClearSpeak; assistive technology; screen reader

doi:10.1002/ets2.12132

Math accessibility for students with visual impairments (SVIs) is a domain that, prior to the project described here, extended, at best, minimally to audio delivery. SVIs could use pre-prepared braille, pre-prepared large print, or various forms of electronic or optical magnification tools, but they could not use a screen reader to read and interactively navigate math expressions, even though screen readers provided text-to-speech (TTS) and interactive navigation for text and many standard Web elements (tables, checkboxes, links, etc.). At best only two options allowed SVIs to work with electronically delivered math: (a) alternate text, which had to be hand-developed and which could be navigated only as text, or (b) TTS (provided by MathPlayer), which had speech patterns that did not closely resemble classroom speech, could not be navigated interactively, required use of a mouse to invoke, worked in only one browser (Internet Explorer), and did not work outside of a browser (importantly, not in Microsoft Word). Adding navigation functionality was important because math expressions beyond the simplest tend to impose excess memory load to track all of the information they contain. Math-specific navigation serves two important goals: (a) providing a way for listeners to work with the specific mathematical structure of each expression, and (b) extending to math a functionality that has long been available for text. The need for navigation is discussed in more detail later in the Background section of this paper and in Frankel and Brownstein (2016). Adding Microsoft Word functionality was important because, although considerable information is posted on the Internet for use with browsers, it is far more common and convenient in day-to-day instruction for teachers and students to work in Word to create and share materials.

This report describes the purpose, methodology, and results of the final pilot study performed for our project, Expanding Audio Access to Mathematics Expressions by Students with Visual Impairments via MathML. The project

Corresponding author: L. Frankel, E-mail: lfrankel@ets.org

was funded by a U.S. Department of Education, Institute of Education Sciences Special Education Development Grant (R324A110355), which supported the iterative development of the ClearSpeak speech style, authoring tools, interactive navigation, and integration with Microsoft Word. Prior to the final pilot, which was conducted in the spring of 2015, development was guided by three feedback studies with SVIs and one with teachers. The feedback studies with SVIs comprised one focusing on comparing two existing speech styles with the new speech style we were developing, one on the use of certain prosodic and lexical elements in the new speech style, and one on the interactive navigation we were developing. The feedback study with teachers focused on authoring using the features of the new speech system. The students in each of the three feedback studies and the portion of the pilot targeting SVIs mirrored our target audience for the tools being developed: secondary school SVIs who were taking or had previously completed Algebra 1, who were proficient in English, and who did not have significant cognitive impairments. The teachers in the authoring feedback study and the portion of the pilot targeting teachers included math teachers, many of whom had little or no experience with SVIs, and teachers of the visually impaired (TVIs) who included math in their teaching duties.

Background

Bouck, Meyer, Joshi, and Schleppebach (2013) conducted a small qualitative study on students using an eText player to read algebra expressions, in which the authors noted that studies of electronic access to math for SVIs had been minimal. Their observation-based study involved three students with mild to severe low vision (none with blindness) who used an eText player that combined TTS with enlargement. The math involved was encoded in MathML, and the TTS used the MathSpeak style, which we had compared in a previous study with the ClearSpeak style we have developed (Frankel, Brownstein, Soiffer, & Hansen, 2016). Bouck *et al.* (2013) used tasks with similarities to those we used in some of our earlier feedback studies: identifying structural features of the math presented, such as how many variables were in a provided math expression. Although the authors informally compared the efficiency of the eText to that of the students' traditional methods, they did not compare the students' ability to identify mathematical features or solve problems using the eText player with their ability to do so using the format they usually used (which was large print for all three students in their study), but they suggested that future research should do so. To our knowledge, our pilot study is the first to attempt such a comparison.

We previously reported on the development and results of our initial studies with SVIs of the ClearSpeak style for synthetic speech of math expressions commonly encountered in high school algebra (Frankel *et al.*, 2016) and on the usefulness and suitability for inclusion in ClearSpeak of certain enhanced prosodic and lexical cues (Frankel & Brownstein, 2016). In the first report, we described advantages found for ClearSpeak over two pre-existing synthetic speech styles (MathSpeak and SimpleSpeak). In the second report, we described our findings that while the prosodic enhancements studied did not appear to improve comprehension of the math expressions studied, certain lexical cues did appear to have some value and that further study into the usefulness of prosodic enhancements might be fruitful. Not surprisingly—and consistent with findings by previous researchers (see, *e.g.*, Bates & Fitzpatrick, 2010, and Ferreira & Freitas, 2005)—both studies suggested that interactive navigation would be an important enhancement to students' ability to understand spoken mathematical expressions, particularly expressions that are long and/or complex. In anticipation of such a finding, we had already planned to incorporate interactive navigation into the speech system we were developing.

We begin this report with the student component of the pilot and then address the authoring component.

Student Pilot

The student pilot compared the complete implementation of ClearSpeak (including all speech rules, preferences, prosodic elements, and navigational support) with each student's usual method of accessing math expressions. The comparisons focused on students' success in solving math problems using the ClearSpeak implementation versus using each student's usual format—braille, regular print (usually with magnification), or large print (possibly with additional magnification). It also compared students' subjective reactions to the ClearSpeak implementation with their subjective reactions to their usual format. We investigated the following specific research questions:

1. How does the spoken math delivery compare with students' usual delivery format (braille or large print) with regard to students' success in solving algebra problems (specifically, in using certain component skills and performing certain authentic tasks, both of which will be described later)?

2. How do students' indications of preference, confidence in solving math problems, and opinions about ease of understanding the math expressions in the spoken math delivery compare with their corresponding indications for their usual delivery format?

Navigation

Discussions with stakeholders, and, as noted previously, our previous work (see Frankel et al., 2016, and Frankel & Brownstein, 2016), and information in the literature (see, e.g., Bates & Fitzpatrick, 2010; Ferreira & Freitas, 2005) strongly confirmed our belief in the importance of interactive navigation for math expressions; accordingly, building that functionality was an important part of this project. This section briefly describes the navigation tools developed, all of which are controlled via keystrokes.

Move Through Expression

The simplest navigation feature allows the user to use the left- and right-arrow keys to move forward or backward through any expression in “chunks,” the size and organization of which are controlled by the zoom in/out and navigation mode settings (described subsequently).

Zoom In/Out

Users can set the chunk size to smaller (zoom in, down-arrow key) or larger (zoom out, up-arrow key).

Set/Access Place Markers

Within an expression, users can assign up to 10 bookmarks and can return as desired to the locations that were bookmarked.

Where Am I

Intended to be useful when zoomed in to a small chunk, this feature indicates the larger context and location of the current chunk.

Expression Overview/Description

This feature provides a simplified overview or description of the expression. For example, in Describe mode, when zoomed all the way out, the expression $\frac{3}{4} + \frac{x+1}{x-1}$ would speak as “fraction plus fraction.” Users use keyboard commands to toggle in and out of Describe mode as desired.

Navigation Mode Options

Three navigation modes are provided. The Character mode reads expressions character-by-character. The Simple and Enhanced modes read expressions in ways that take more of the mathematical meaning into account, with Enhanced mode making the greatest use of mathematical meaning in the way it chunks the expressions.

Method

Participants

All participants had visual disabilities (blindness or low vision). Each participating student was taking or had completed Algebra 1, was fluent in English, and did not have a significant cognitive disability. Demographic details are shown in Table 1.

Table 1 Participant Characteristics ($N = 21$)

Characteristic	N
Blind (i.e., always or primarily use nonvisual methods to access math)	7
Low vision	14
Age range	15–19 (median: 16)
Grade range	9–12 (median: 10)
Current or most recent math class	Algebra 1: 8 Math models: 3 Geometry: 5 Algebra 2: 3 College algebra: 1 Statistics: 1
Attending a school for the blind	14
Attending school in inclusive setting	7

Sampling Procedures

Participants were recruited through one participating school for the blind and through a consultant who recruited students being educated in inclusive settings. Seventeen of the 21 students participating in the pilot had also participated in our previous feedback study on navigation. Students were given \$125 in gift cards for completing the pilot. Institutional Review Board approval and signed informed consent forms were obtained prior to data collection.

Research Design

Instruments

The student component of the pilot study used the following five instruments.

Navigation Tutorial and Feedback

In the navigation tutorial (see Frankel, Brownstein, & Noble, 2015 for the final version), students worked through an introduction, which provided information on using the NVDA screen reader with Word and some general instructions, followed by seven lessons, which covered the following topics:

- Basics of reading and navigating math expressions, using arrow keys to move through an expression and zoom in/out of it
- Using the three available navigation modes (Character, Simple, and Enhanced)
- Using the Where Am I tool to locate parts of an expression within the larger expression
- Using two speech modes: Read Math and Describe Math
- Using place markers to bookmark parts of a math expression and return to the locations that were bookmarked
- Useful strategies for navigating math expressions
- Additional practice expressions

Both the navigation functionality and the tutorial used in the pilot had been revised based on information provided by students in the navigation feedback study, which included an extensive questionnaire regarding participants' impressions of each navigation tool and of the portions of the tutorial that taught how to use that tool. In the pilot, some navigation feedback questions were asked at the end of the spoken math instrument (described subsequently, and provided in Appendix A) and focused on the students' use of and preferences for the three navigation modes, based on their experiences having spent time actually using the system to respond to math questions. Additional feedback on all formats used by each student was requested in the instruments given after the print or braille math section, after the spoken math section, and after both math sections had been completed. Feedback instruments are provided in Appendix B.

In addition to the instruments, these materials were supplied in braille, regular print (for use with a video magnifier (CCTV), and large print (18 and 24 point):

- *Navigation Quick Reference Guide*. This table indicated the functions of important keystrokes.

- *Expression Supplement for Navigation Tutorial.* The navigation tutorial included several math expressions as examples for learning the interactive navigation system. Students used the supplement to follow along, using a familiar format, as the computer read and navigated each expression, as an additional support to help them gain confidence that they understand the expression and how the navigation works. The tutorial also included (in Lesson 7) practice expressions that were not included in the expression supplement. These practice expressions, without accompanying print or braille versions, served as a self-check for students to perform before they moved on to the spoken math instrument.

Math Instrument

The pilot included two parallel math instruments: one in a Word document (provided in two base font sizes: 12 and 24) to be used with the speech and navigation system, and another for which students could select braille, regular print for CCTV, or large print (18 or 24 point, which could also be used with magnification if desired). Results on the spoken math section (and on each individual spoken math problem vs. its nonspoken counterpart) were compared for each student with results on the section in the nonspoken format the student preferred as most like the format they usually used. The math instrument (see Appendix A) consisted of six parts, each with one or more examples (with correct answers) and two to five math questions. The math questions in the instrument were appropriate to students who were in or had completed Algebra 1 and focused on expressions and problems for which it was helpful to be able to keep track of various components of the expression, such as numbers of decimal places in a long decimal number, paired parentheses in an expression with multiple levels of nested parentheses, or exponents in a polynomial. Tasks included simplifying and evaluating expressions and identifying specific features of an expression, such as the number of decimal places, number of terms in a polynomial, or the parts of the numerator/denominator of an algebraic fraction that could “cancel” each other.

Feedback Instruments

Each medium (braille, print, spoken) had an associated feedback instrument (see Appendix B) given directly after completion of the corresponding math instrument. Two questions were common across all formats: (a) a multiple-choice question, “How easy was it to understand what the expressions in the section were? (very easy/somewhat easy/somewhat hard/very hard),” and (b) an open-ended request for students to describe how the particular spoken, printed, or brailled presentation of the math expressions made them easy or hard to work with and suggestions for how the presentation could be improved. The other feedback questions were more format specific. The spoken feedback section included questions about each of the navigation tools, focusing on the extent to which the tool helped (or did not help) to make spoken math expressions easier to work with. The print feedback section included questions about any magnification tools the student used. A final feedback instrument (also in Appendix B) was given after the student had completed both (spoken and nonspoken) math instruments and their associated feedback instruments. Students were asked to compare the spoken math section to the braille or print section in various ways: which one they preferred and to what extent, their impressions of relative lengths of the sections, and a comparison of levels of confidence in their answers to the spoken versus nonspoken (braille or print) versions of math questions.

In the student background questionnaire (Appendix C), students were asked to self-report their math- and vision-related background and their history with using various forms of assistive technology for math.

The student background questionnaire for teachers (Appendix C) was a parallel instrument to the questionnaire for students; teachers were asked the same questions (on behalf of their students) that the students had answered for themselves. Central topics of the two questionnaires included the following:

- Student’s current best mode for accessing math (print, braille, read aloud, various types of assistive technology)
- Perceived usefulness for the student of the various modes for accessing math (print, braille, read aloud, various types of assistive technology)
- Student’s proficiency with fractions, square roots, and parentheses (grouping), which were the math topics covered in the instrument.
- Degree to which the student uses visual versus nonvisual methods of accessing math
- Hoped-for features in a system that allows screen readers to read math

Table 2 Instrument Order

Sequence	Group 1 (<i>n</i> = 10)	Group 2 (<i>n</i> = 11)
1	Student background questionnaire/student background questionnaire for teachers	Student background questionnaire/student background questionnaire for teachers
2	Navigation tutorial	Nonspoken (print or braille) instrument
3	Spoken math instrument	Nonspoken (print or braille) feedback instrument
4	Spoken math feedback instrument	Navigation tutorial
5	Nonspoken (print or braille) instrument	Spoken math instrument
6	Nonspoken (print or braille) feedback instrument	Spoken math feedback instrument
7	Final feedback instrument (comparing spoken and nonspoken formats)	Final feedback instrument (comparing spoken and nonspoken formats)

Table 3 Material Formats Supplied

Document	Read aloud	Word	Print	Braille (Nemeth Code)
Student background survey (student responses)	x			
Student background survey (teacher responses)		x	x	
Study introduction	x			
Navigation tutorial		10 point 24 point		
Navigation quick reference guide			11 point 13 point 18 point 24 point	x
Navigation tutorial expression supplement			12 point 14 point 18 point 24 point	x
Math instrument (spoken)		12 point 24 point		
Math instrument (nonspoken)			12 point 24 point	x
Spoken math feedback	x	10 point		
Nonspoken math feedback	x	x		
Final feedback	x	x		

Note. An “x” indicates that material was provided in this format. Material provided in varying point sizes is also noted.

Study Manipulation

Each student received the spoken math instrument and an instrument in their chosen nonspoken (e.g., print or braille) format. Participants were divided randomly into two groups to receive materials in different orders, shown in Table 2.

Formats Provided

As alluded to previously, materials were supplied in various formats. Table 3 shows all materials and their formats. Where multiple formats were provided, students could select the formats they preferred. Printed materials were sometimes used with CCTVs for further magnification. The Word-formatted materials were delivered on computers on which the study software (Microsoft Word, MathType, MathPlayer, and a version of NVDA with MathPlayer support) had been installed. Students could use Word’s built-in zoom in/out features to further refine the size of the displayed text and math.

Session Procedure

1. Students completed the background survey with the help of the study administrator, who also collected parallel information from the student’s math and VI teachers.

2. Administrators read an introductory statement aloud. The statement described the purpose of the study and the procedures that would be followed. Students were reminded that their participation was voluntary and that they could withdraw at any time without penalty. They were informed that they were permitted to use any assistive technology they liked for note taking, to repeat the spoken expressions as desired, and to take breaks as needed. Breaks were also explicitly offered between instruments.
3. Roughly half of the students followed the sequence 3a, 3b; the other half followed the sequence 3b, 3a, as described next (and shown in Table 2).
 - 3a. Spoken Math: Students were given the interactive navigation tutorial (a Word document that both instructed them in how to navigate math expressions and asked them to navigate the expressions provided as they were spoken). Because the pilot was intended to mimic an authentic environment, the large-font version of the tutorial also enlarged the math expressions to match the font size of the text. After completing the navigation tutorial, students began the spoken math instrument. At the beginning of the spoken math instrument, students were asked to explore two math expressions as a warm-up to select their starting navigation mode (which they could change as desired) from the three modes provided (Character, Simple, and Enhanced) and taught in the navigation tutorial. Then they completed the spoken math instrument and the spoken math feedback instrument.
 - 3b. Nonspoken (Braille, Regular Print or Large Print) Math: Students selected their preferred format; if selecting a print format, used magnification devices as desired; and completed the nonspoken instrument, entering their own responses or having them scribed by the study administrator. Then students completed the feedback instrument corresponding to their selected format.
4. Students completed the final feedback instrument, which invited them to make comparisons between the spoken math presentation and the print or braille presentation.
5. Students completing the study received gift cards.

Qualifications of Study Administrators

Study administrators were either project consultants who worked at one of the cooperating schools or cooperating school personnel.

Development of the Math Items

With consultation from two of our expert consultants—Susan Osterhaus and Maylene Bird (both teach math to students who are blind or visually impaired)—we crafted items that used concepts taught in Pre-Algebra, Algebra 1, and Algebra 2. The items involved either authentic tasks (types of problems students would be asked to do in math classes) or tasks that, while they might not be directly assigned in class, represented component skills that are needed in order to solve typical math problems, such as determining the number of decimal places in a number or identifying parts of an algebraic fraction that could be canceled out in order to simplify the fraction.

The instrument was divided into six parts, each of which was devoted to a particular skill. Each part began with a sample item, which included the correct answer, and then varying numbers of items of increasing difficulty. The following skills were represented:

- Determining the number of zeroes to the right of the decimal point (component skill)
- Identifying features of polynomials (identifying number of terms, coefficients, specific terms, and degree—all component skills)
- Simplifying algebraic expressions (authentic task)
- Calculating the value of numerical expressions (authentic task)
- Simplifying algebraic fractions (authentic task)
- Simplifying exponential expressions (authentic task)

After the base items were developed, reviewed by our expert consultants, and finalized, we produced the “clone” items so that two parallel forms (spoken and braille or print) could be given to each student. The order of the base items in the

form was maintained in the parallel forms. The clones were also reviewed for comparability to the corresponding base item before being finalized.

Data Analysis

All responses were entered into an Access database. Where appropriate, scores for responses were calculated. Responses to math questions were scored 1 (*correct*) or 0 (*incorrect*).

Results (Student Pilot)

Quantitative Results by Research Question

Because of the small sample, quantitative analysis is descriptive only. This section describes how our pilot results bear on each of the two research questions stated previously:

1. How does the spoken math delivery compare with students' usual delivery format (braille or large print) with regard to students' success in solving algebra problems (specifically, in using the component skills and performing the authentic tasks described previously)?
2. How do students' indications of preference, confidence in solving math problems, and opinions about ease of understanding the math expressions in the spoken math delivery compare with their corresponding indications for their usual delivery format?

Research Question 1. Comparisons of Success in Solving Algebra Problems

All 21 students took both the spoken math (ClearSpeak) section and a nonspoken math section. For their nonspoken math section, 13 students elected to take a print version and eight elected to take a braille version. Because each of the math questions in the nonspoken section had a corresponding clone in the spoken section, we were able to compare students' success in answering math questions (spoken vs. nonspoken format) by pairing each spoken math question with its clone and computing a net score for the pair for each student. Each student's net score on each of these pairs of questions was calculated as follows.

- When the student answered both the spoken question and its nonspoken clone correctly or both incorrectly, the net score for the pair was 0.
- When the student answered the spoken question correctly and its nonspoken clone incorrectly, the net score for the pair was 1.
- When the student answered the spoken question incorrectly and its nonspoken clone correctly, the net score for the pair was -1 .

We also calculated net scores by expression pair by comparing the number of students correctly answering the spoken member of the pair to the number correctly answering the nonspoken (print or braille) member of the pair. A negative net score for a question pair indicated that fewer of the students correctly answered the spoken member of the question pair than the nonspoken member of the same pair; a positive net score for a question pair indicated that more of the students correctly answered the spoken member of the question pair than the nonspoken member of the same pair; and a net score of 0 for a question pair indicated that the same number of students answered the spoken member of the question pair correctly as answered the nonspoken member of the pair correctly.

We analyzed the net scores by question pair and by student. The results of these analyses are shown in Tables 4 and 5. Table 4 shows how many of the students answered the spoken and nonspoken version question in each question pair correctly and the net score for that question pair. The average net score per question pair was 0.125 (*SD* 2.73). Table 4 shows that for all but two question pairs, the net scores were between -2 and 2; one question pair had a net score of 6, and another had a net score of -6 .

Table 5 shows that for each of the students, the difference between the number of math questions answered correctly in the 16 question spoken math section and the number of math questions answered correctly in the 16 question nonspoken section was at most 2.

Table 4 Net (Spoken vs. Nonspoken) Scores by Question Pair, Aggregated Across Students

Math question pair	All students ($N = 21$)			Print users ($n = 13$)			Braille users ($n = 8$)		
	Net score	Number answering spoken question correctly	Number answering nonspoken question correctly	Net Score	Number answering spoken question correctly	Number answering print question correctly	Net Score	Number answering spoken question correctly	Number answering braille question correctly
1.1	-1	20	21	-1	12	13	0	8	8
1.2	-2	18	20	-2	10	12	0	8	8
2.1	0	19	19	-1	11	12	1	8	7
2.2	2	21	19	2	13	11	0	8	8
2.3	-2	19	21	-1	12	13	-1	7	8
2.4	2	21	19	2	13	11	0	8	8
2.5	0	20	20	0	12	12	0	8	8
3.1	-1	19	20	1	13	12	-2	6	8
3.2	-6	9	15	-2	6	8	-4	3	7
4.1	2	17	15	-1	10	11	3	7	4
4.2	0	7	7	0	4	4	0	3	3
4.3	6	13	7	3	9	6	3	4	1
5.1	2	13	11	1	9	8	1	4	3
5.2	-1	13	14	1	9	8	-2	4	6
6.1	3	20	17	1	12	11	2	8	6
6.2	-2	7	9	-1	5	6	-1	2	3

We also calculated the mean and standard deviation of scores per question by delivery mode and, within the spoken delivery mode, by students' visual status (blind or low vision). Results are shown in Table 6.

The comparisons shown in Tables 4, 5, and 6 indicate that students performed very similarly on the spoken math version and on the version in their usual format. In this case, lack of clear difference is notable, because it suggests that the spoken math format affords students a comparable level of support for answering the math questions to that provided by braille and print formats.

Research Question 2. Preference, Confidence, and Understandability

Each student answered feedback questions pertaining to the spoken format and to the particular nonspoken format used by the student. One question, pertaining to ease of understanding math expressions, was common to all formats; other feedback questions were format specific. In the final feedback questionnaire, given after students had completed math instruments in both formats, although few students expressed strong format preferences; most, but not all of those preferred their usual method. Only two (about 10%) indicated they would prefer to avoid the spoken format. Full results are in Table 7.

To look for potential explanations of the strongest preferences expressed, we looked at other data from the relevant students. For the two students who would always prefer their usual method (braille in one case, print in the other) and for the one student who would always prefer the spoken math over the student's usual method (print, in this case), their math scores in the spoken section were all slightly higher than (two more correct responses) or equal to their scores in the section in their usual format. Comparisons of time spent per section were likewise uninformative: Of the two who strongly preferred their usual method, one took slightly less time on the spoken section; the other, considerably more time. The student who strongly preferred the spoken method took considerably more time on the spoken section than on the printed section. So the data do not suggest to us an explanation for the strongest preferences in either direction.

When students were asked, in the feedback sections following each of their two math instruments, how easy or difficult it was to understand the math in the particular format, almost all of the students reported finding the math at least somewhat easy to understand in both formats they received. For the spoken math, most found it somewhat easy to understand, while in their usual format, most found it very easy to understand, as seen in Table 8. Note that unlike the responses reported in Table 7, the evaluations shown in Table 8 were not posed as a direct comparison between the two formats; rather, they were posed immediately following the applicable math instrument.

Table 5 Net (Spoken vs. Nonspoken) and Per Format Scores by Student ($N = 21$), Aggregated Across Question Pairs and Sorted by Net Score, Showing Selected Demographic Information From the Background Questionnaire

Net	Spoken ^a	Print ^a	Braille ^a	Current/most recent math class	Vision status	Usual medium	Best medium
2	15	13	n/a	Algebra 1	LV	Large print	Large print
2	15	n/a	13	Algebra 1	B	Braille	Human reader
2	16	14	n/a	Algebra 2	LV	CCTV	CCTV
2	13	11	n/a	Algebra 2	LV	CCTV	CCTV
2	14	n/a	12	Algebra 1	B	Human reader	Braille
1	13	12	n/a	Geometry	LV	CCTV	Large print
1	13	12	n/a	Algebra 1	LV	CCTV	CCTV
0	14	14	n/a	Geometry	LV	Human reader	CCTV
0	14	14	n/a	College algebra	LV	CCTV	CCTV
0	11	n/a	11	Geometry	B	Braille	Braille
0	10	n/a	10	Math Models	B	Braille	Braille
0	13	n/a	13	Math Models	LV	Braille	Braille
0	14	14	n/a	Algebra 2	LV	Enlarged on screen	Human reader
-1	11	12	n/a	Geometry	LV	Large print	Large print
-1	9	10	n/a	Algebra 1	LV	Enlarged on screen	Enlarged on screen
-1	10	n/a	11	Algebra 1	B	Braille	Braille
-1	11	12	n/a	Geometry	LV	CCTV	CCTV
-1	5	6	n/a	Math Models	LV	CCTV	Human reader
-1	12	n/a	13	Statistics	B	Refreshable braille	Braille
-2	11	n/a	13	Algebra 1	B	Braille	Braille
-2	12	14	n/a	Algebra 1	LV	CCTV	CCTV

Note. B = blind; LV = low vision.

^aMaximum score = 16.

Table 6 Mean and Standard Deviations of Students' Average Scores per Question Overall, by Visual Status For Spoken Instrument and by Delivery Format for Nonspoken Instrument

Statistic	Spoken			Nonspoken		
	All ($N = 21$)	Blind ($n = 8$)	Low vision ($n = 13$)	All ($N = 21$)	Braille ($n = 8$)	Print ($n = 13$)
Mean	0.762	0.741	0.772	0.756	0.750	0.760
SD	0.427	0.440	0.440	0.430	0.435	0.428

Note. All students classified as "blind" used braille as their nonspoken format. All students classified as "low vision" used print as their nonspoken format.

Looking at individual students, Table 9 shows that most students considered their usual format to be very easy to understand and the spoken format to be somewhat easy, but a few found both formats very easy or found both somewhat easy, and two braille users found the spoken format easier than braille. Students who used braille as their nonspoken format more frequently rated the spoken format as very easy than did the students who used print as their nonspoken format.

In the spoken format feedback questionnaire, students were asked whether each of the various navigation features made the spoken math much easier, somewhat easier, slightly easier, or no easier to understand or work with. Their responses are in Table 10. One student responded to the first of this series of questions, "I never entered math [navigation mode] but it seemed easy in the tutorial. The gestures were straightforward and allow for more control in the problem." That student (who used 12-point print with CCTV for the nonspoken math section) then referred to this statement when responding to the remainder of the questions in the series. For that reason, there are 20, not 21 responses to each question shown in Table 10. The table shows that the functionalities for arrow keys, zooming in/out, and switching navigation modes were very well-liked, that the place-marker feature had mixed reviews, and that the Where Am I and Describe features did not appear very useful to the students. With particular respect to navigation modes (essentially, these are ways in which

Table 7 Students' Format Preferences, Based on Responses to Final Feedback Questionnaire

Statement	Number of students selecting (N = 21)	Approximate percentage of students selecting
I would always prefer my usual method, and would not want to use the spoken math if I didn't have to.	2	10%
I would usually or always prefer my usual method, but the spoken math is ok.	8	38%
I prefer them about equally, and it might depend on the type of math or situation which one I would prefer at a particular time.	7	33%
I would usually or always prefer the spoken math but my usual method is ok	0	0%
I would always prefer the spoken math, and would not want to go back to using my usual method if I didn't have to.	1	5%
I would sometimes like to use my usual method and the spoken math together.	3	14%

Table 8 Students' Answers to Questions of How Easy They Found the Math Expressions to Understand, by Format

Understandability	Spoken (N = 21)	Braille (n = 8)	Print (n = 13)
Very easy	9	6	11
Somewhat easy	12	1	2
Somewhat hard	0	1	0
Very hard	0	0	0

expressions are “chunked” for navigation), each of the three modes offered was listed by several students as the student's favorite mode, while two students declined to indicate a favorite.

Qualitative Findings

Students' responses to the open-ended questions were overwhelmingly positive, with some providing specific suggestions for enhancements. The following is a representative sampling of students' responses:

- This was the best way math could be done in speech.
- I could understand it with less eye strain than just using sight. If I could get the high-contrast setting in Windows to display the math in inverted colors, that would be even better, but it only changes the color of the text and not the math.
- Having it read term by term was helpful.
- It was hard to slow down when you need to hear the math problems.
- It was easy enough that I would not need to look to understand the problems.
- It was easy to work with. I understood it very easily.
- The math was very easy to understand my only comment would be having to enter math mode right when the voice says math because that can get frustrating at times when you have to make sure the cursor is right on the math or the voice right in that moment or you won't be able to enter math mode.
- There was little to no trouble for me in terms of understanding the math questions. However, every time a term was squared, the software would say “to the second” instead of the typical “squared.” That made at a little confusing initially, but I soon grew accustomed to it.
- The math expressions were read beautifully. I could understand everything even better than I could reading them in braille (Nemeth code).

Authoring Pilot

An important component of the tools developed were those that allow teachers or other content providers to create accessible math expressions for use by SVIs who use the tools developed for students. Prior to the authoring pilot, we had

Table 9 Ease of Understandability by Student and Format

Student	Very easy	Somewhat easy	Somewhat hard	Very hard
Students using print as their nonspoken format ($n = 13$)				
KY-01	P	S		
KY-02	PS			
KY-04	P	S		
KY-05	P	S		
KY-06	P	S		
TX-01	PS			
TX-04	P	S		
TX-05	P	S		
TX-06	PS			
TX-07		PS		
TX-09	PS			
TX-12		PS		
TX-14	P	S		
Students using braille as their nonspoken format ($n = 8$)				
KY-03		S	B	
KY-07	B	S		
TX-02	B	S		
TX-03	BS			
TX-08	BS			
TX-10	BS			
TX-11	S	B		
TX-13	BS			

Note. B = braille; P = print; S = spoken.

Table 10 Students' Answers to Questions About Usefulness of Navigation Features

Using feature made spoken math	Much easier to understand/ work with	Somewhat easier to understand/ work with	Slightly easier to understand/ work with	No easier to understand/ work with
Arrow keys	14	4	2	0
Zoom in/out	14	5	0	1
Switch navigation modes	13	4	2	1
Place markers	7	4	6	3
Where Am I	3	5	2	9
Describe	2	5	1	12

Note. $N = 20$. One student did not use navigation features.

conducted an authoring feedback study in which participating teachers worked through a tutorial, practiced authoring accessible math expressions, and answered feedback questions about both the tutorial and the usability of the authoring tools. Based on the feedback received (which was highly positive), we made adjustments prior to conducting the pilot. The authoring pilot was designed to address the following research questions:

1. Are teachers able to author math content so that it speaks as intended?
2. Do teachers find authoring easy and that the tutorial is helpful in preparing them to author math content so that it speaks as intended?
3. Do teachers find the overall functionality useful and usable?

Authoring Tasks

Authoring accessible mathematics, in broadest terms, requires (a) creating math expressions that are encoded in MathML and (b) ensuring that those expressions are spoken as intended. These tasks are performed within Microsoft Word using MathType and MathPlayer.

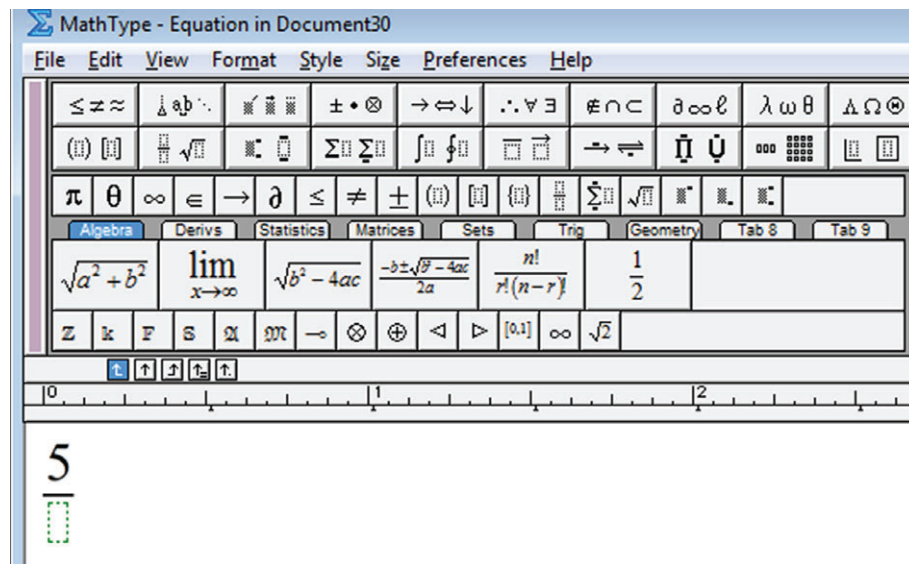


Figure 1 An expression is being created in MathType.

Creating Math Expressions

MathType provides interactive templates, integrated with Word, for entering MathType objects, which are displayed in Word as scalable graphics (which, unlike bitmapped graphics, enlarge smoothly) and which include MathML “under the hood,” which supports the speech. MathType as a method for creating math expressions pre-existed our project; our project added support for authoring and playing back speech within Microsoft Word. Figure 1 shows a MathType window as an expression is being created.

Ensuring Correct Speech

As discussed in more detail elsewhere (Frankel et al., 2016), spoken math in MathPlayer is generated from the underlying MathML encoding using a combination of *rules*, *preferences*, and *exact speech*. Rules are default ways of speaking math structures. *Preferences*, which can set by authors, are variants of the rules. Some rules and preferences vary the speech of an expression depending on details in the content of the expression. Authors can use preferences to adjust the speech when the rules do not produce the desired results for any reason. For example, according to the rules, the fraction $\frac{5}{9}$ is spoken as “five ninths” and the fraction $\frac{12}{23}$ is spoken as “twelve over twenty-three.” An author of an expression that contains both of these fractions could use the *Fraction_Over* preference to adjust the speech of the first fraction to “five over nine” to make the two fractions speak consistently. The capability developed to set MathType preferences for speech leverages a pre-existing MathType capability for setting print/display preferences (font, size, etc.). To invoke the *Fraction_Over* preference to make $\frac{5}{9}$ speak as “five over nine,” an author need only select that preference from a MathType menu, as shown in Figure 2.

Exact speech allows a content author to enter custom wording, which can include pauses of author-specified length or adjustments to rate or pitch. Exact speech is intended to be used (and authors are cautioned to use it) only when the necessary speech cannot be generated using the rules and preferences, and it should be applied to the smallest portion of the expression possible. Exact speech should be limited in this way because it can have unintended effects on how an expression is navigated. Exact speech (called “custom speech text” in MathType) can be typed into an editing window. For example, if the desired speech for $\frac{5}{9}$ is “five out of nine,” that could simply be entered into the Custom Speech Text window, as shown in Figure 3. After being set, exact speech can be edited or removed if desired.

After creating an expression and (if needed) assigning speech preferences or exact speech to it, an author can listen to the expression or interactively navigate it using in the *Speak* or *Navigate* buttons, respectively, that are included in the MathPlayer toolbar. (An author might wish to check navigation to see the effect of any exact speech set.) To listen to an expression or to navigate it as it is spoken, the user selects the expression and clicks the appropriate button, as shown

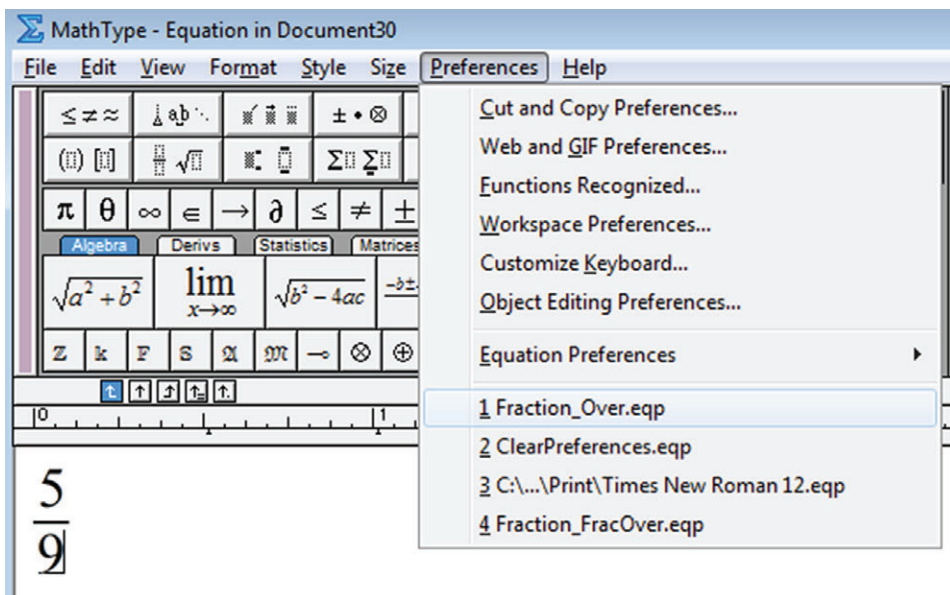


Figure 2 Author setting a speech preference for fractions.

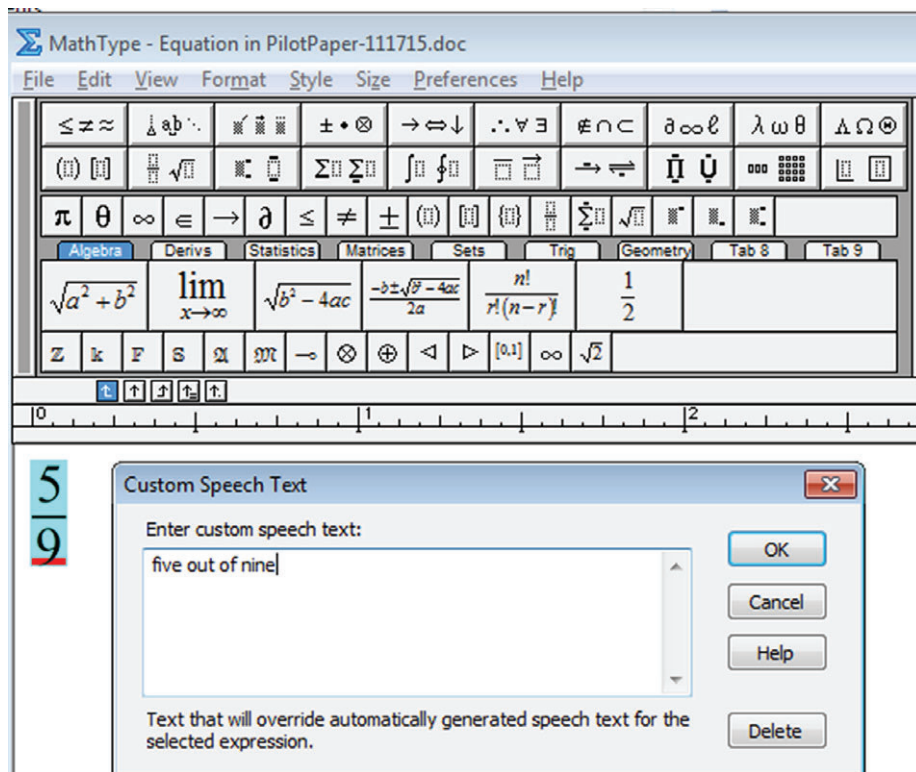


Figure 3 Exact speech is created in the Custom Speech Text window.

in Figure 4. Note that the use of the speech and navigation buttons is intended primarily for sighted users. Although expressions can also be selected and the Speak or Navigate buttons activated using the keyboard, the more natural method for eyes-free use is to use the NVDA screen reader,¹ which fully integrates the math speech and navigation for nonvisual access to math within the Word document.²

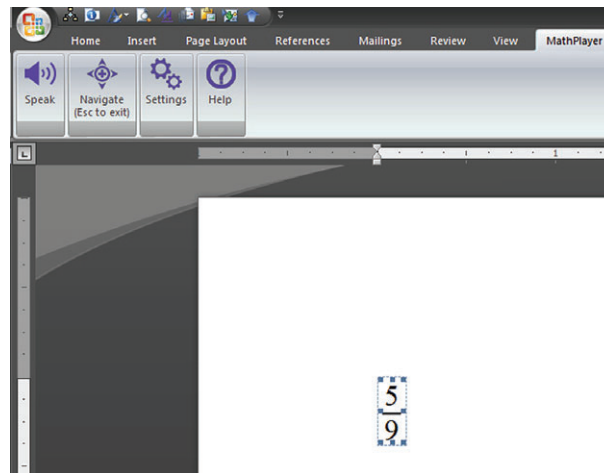


Figure 4 The Speak and Navigate buttons allow the author to listen to and navigate an expression.

Table 11 Number of Students Who Are Blind or Visually Impaired Taught in the Past 5 Years

No. of students	Visually impaired	Blind
None	4	9
1–2	5	0
3–5	0	1
5–10	1	2
10–20	1	0
>20	1	0

Table 12 Math Classes Taught

Class	No. of teachers
Pre-algebra	2
Algebra 1	5
Algebra 2	7
College algebra	1
Other algebra	2
Geometry	7
Pre-calculus	5

Method

Participants

Twelve teachers participated in the authoring pilot. Ten participants were math teachers and two participants were TVIs. Additional characteristics are in Tables 11–17. Note that counts do not all sum to 12 because some questions allowed for multiple answers and/or no answer if none of the choices applied.

Sampling Procedures

Participants were recruited through one participating school for the blind, through a consultant who recruited itinerant teachers and teachers in inclusive settings, and via networking. Four of the 12 participants had also participated in the authoring feedback study. Participants were given \$125 in gift cards for completing the pilot. IRB approval and signed informed consent forms were obtained prior to data collection.

Table 13 Years of Math Teaching Experience

Years of teaching experience	No. of teachers
<5	5
5–10	3
10–20	3
>20	0
Not answered	1

Table 14 Teaching Environment

Teaching environment	No. of teachers
School for the blind or visually impaired	2
Itinerant ^a	2
Inclusive classroom	7
Not answered	1

^aTVIs who work at several different schools to provide services to individual students.

Table 15 Experience With Math Tools/Assistive Technology

Assistive technology	No. with experience
MathType	9
MathPlayer	1
Scientific notebook	2
Other math tool	4

Research Design

Instruments

The authoring component of the pilot study used the following instruments.

Background Questionnaire

Teachers were asked to self-report their experience teaching math and SVIs and using assistive technology in their teaching in the background questionnaire (Appendix C).

Authoring Tutorial

The authoring tutorial provided instructions, with step-by-step illustrations, and a separate workbook for participants to use to create expressions and assign speech to them as instructed by the tutorial. The tutorial covered the following topics:

- Using MathType to enter math expressions
- Setting and clearing preferences
- Entering and removing exact speech
- Listening to the resulting speech to verify that the math is spoken as intended

This tutorial had been modified to respond to comments received in the feedback study, incorporate updates to functionality, and remove a fourth topic, creating custom preference files, which many of the participants in the authoring feedback study had found too difficult and were not sure they would use. A version of that topic has been restored as an optional advanced section in the final published version of the tutorial (Brownstein & Frankel, 2015).

Table 16 Experience With Screen Readers

Assistive technology	No. with experience
JAWS	2
NVDA	2
VoiceOver	3

Table 17 Experience With Screen Magnifiers

Screen magnifier	No. with experience
ZoomText	3
Other magnifier	2

Authoring Assessment

In the authoring assessment (Appendix D), participants were asked to create 11 math expressions and ensure that each expression was spoken in a specified way. The expressions assigned to authors were the same expressions as those given to the students in spoken math instrument of the student pilot. Participants were reminded that, as needed, they could refer to the authoring tutorial and the provided reference material. They could also listen to the speech resulting from their authoring efforts and make changes as needed to achieve the required speech.

Reference Material

In addition to the instruments, participants were provided with a reference document that explained the speech rules and preferences to be used while authoring the spoken math expressions. They were reminded that the reference document could be used both during the tutorial and while taking the authoring assessment. This reference document is an abbreviated version of the ClearSpeak rules and preferences documentation (Brownstein, Soiffer, & Frankel, 2015a and 2015b).

Authoring Feedback

The authoring feedback instrument (Appendix B) includes questions about the ease or difficulty of the tasks in the authoring assessment and about the helpfulness of the tutorial and reference guide. Teachers had the opportunity to answer multiple-choice questions and to provide free-response comments.

Study Manipulation

This study was intended to assess usability, rather than compare treatments, so all participants received the same materials and instructions.

Qualifications of Study Administrators

Study administrators were either project consultants who worked at one of the cooperating schools or cooperating school personnel. For the authoring study, administrators managed recruitment of participants, distribution and return of the laptops, and distribution of gift cards. In one case (a participant not connected to one of the participating schools), we performed the administration responsibilities ourselves.

Session Procedure

For most participants, we provided laptops with all necessary software and documents preinstalled; in other cases, where laptop availability or distance was a factor, participants were provided with the software and installation instructions (and

Expression 1: $1 + \sqrt{2x + y} - z$

Desired Speech:

1 plus the square root of 2x plus y, minus z

Enter Expression 1 here:

Figure 5 Authoring task example.

support as needed). We were assessing only the usability of the tutorial, reference material, and authoring functionality, not ease of installation. Participants worked on their own schedules and were instructed to complete the provided materials in the following order and then return the documents to us:

- Background survey
- Pilot workbook
- Pilot authoring assessment
- Pilot authoring feedback

Once we received the completed materials, participants were given the gift cards.

Development of the Tasks

Because we were trying to simulate a classroom use-case, participants were asked in the authoring assessment to author the same expressions that were provided to the students in the student pilot (the students were not given the documents authored by the teacher-participants, but rather materials created and checked by us). For each of the 11 math expressions in the assessment, participants were told how the expression should speak and were instructed to use the information from the tutorial and reference material as needed while authoring the expressions. They were also reminded to use exact speech only when they could not get the expression to speak as indicated by using the rules and preferences. Figure 5 is an example; the full instrument is in Appendix D. Note that the expressions presented for authoring were provided as images, not as authored MathType objects, so participants were prevented from simply copying and pasting the expressions.

Data Analysis

All feedback responses were entered into an Access database. The authoring tasks were first analyzed and coded for the following characteristics:

- *Speaks correctly?* (Determined by listening to the resulting speech)
- *Authored correctly?* (Determined by examining the preferences the participant had set, and the use, if any, of exact speech)

The coding was then entered into the database, along with any comments received from the participant. Each coding was a yes/no decision. Expressions that were not authored correctly (even if they were spoken correctly) required additional coding to indicate the type(s) of authoring errors, as follows:

- *Used exact speech for entire expression?* (This practice was explicitly discouraged because it can adversely affect navigation; cases where the participant did so anyway were coded as authoring errors of this type.)
- *Excess exact speech?* (Marked in cases where the participant, though not using exact speech for the entire expression, used more exact speech than was in fact needed to produce the assigned speech)
- *Wrong preference?* (Marked in cases where the participant did not select the correct preference for producing the assigned speech)
- *Wrong pause syntax?* (The assigned speech for some questions required entry of pauses in exact speech; if a participant used incorrect syntax for entering the pauses, this was coded.)

- *Wrong preference, minimal exact speech?* (Coded in cases where a participant used an incorrect preference to achieve the assigned speech, but corrected the resulting incorrect speech using only the amount of exact speech necessary to do so)

Results (Authoring Pilot)

Quantitative Results

Because of the small sample, quantitative analysis is descriptive only. This section describes how our pilot results bear on each of the three research questions previously stated:

1. Are teachers able to author math content so that it speaks as intended?
2. Do teachers find authoring easy, and that the tutorial is helpful in preparing them to author math content so that it speaks as intended?
3. Do teachers find the overall functionality useful and usable?

Research Question 1. Authoring Success

Most of the 11 expressions were authored correctly by most of the 12 participants, but some participants, while producing correct speech, did so in ways that were not fully correct (e.g., by using exact speech when preferences were available to achieve the assigned speech). The most salient details are in Table 18.

The most common types of authoring errors committed were using exact speech for the entire expression (two participants each made this type of error five times) and using the wrong preference (one participant made this type of error four times). While each instance of incorrect speech resulted from errors in authoring, not every authoring error resulted in incorrect speech because, for example, an author could select an incorrect speech preference but then apply exact speech to achieve the desired speech.

Research Question 2. Ease of Authoring and Usefulness of Tutorial

In one feedback question, participants were asked how helpful they found the tutorial, with all 12 participants saying they found it very helpful (the highest rating). In another feedback question, participants were asked to rate how easy or difficult they found the authoring tasks. Responses are shown in Table 19.

Research Question 3. Impressions of Overall Functionality

Like the participants in the student pilot, the authoring pilot participants were also quite positive in their comments. The following responses were given to the request for comments on the authoring functionality:

- Seemed to function great. I'd like to be able to continue through my document as the ClearSpeak is talking.
- I thought the tutorial was really good. I felt really confident in using the speech tools and only missed I think 3 on the first try. So, I had a good idea of what auto would do vs. the other settings.
- I think the process is pretty solid. I think it is a good idea to walk through the tutorial and listen to the ways it speaks before you try on your own (good teaching practice!). I was able to quickly figure out which Preference to set because of the practice in the tutorial.
- Have the instructions in a three ring binder or spiral binding so that flipping through is not such a pain. I ripped the staple out and paper clipped the instructions back together, but then the pages started to get out of order.
- I think this ClearSpeak—MathPlayer—MathType “wonderfulness” has great potential. I can't think of anything right now to improve the authoring functionality but I'm going to spend time with it and also try it using NVDA with my eyes closed and have a few students with varying levels of VI give it a try and get their feedback and ideas (if that's permissible or when it is).
- It was much simpler and intuitive than I had anticipated—I was pleasantly surprised. It didn't take me nearly as much time as I had planned.

Table 18 Authoring Correctness, Sorted by Number Correct

Participant code	Number of expressions (<i>N</i> = 11) with correct speech	Number of expressions (<i>N</i> = 11) authored correctly
KY-04	11	11
KY-09	11	11
R-01	11	11
KY-01	11	10
KY-08	11	10
R-02	11	10
T-01	11	9
KY-02	10	9
KY-07	10	9
KY-05	9	5
KY-03	8	6
KY-06	7	7

Table 19 Ease of Authoring (*N* = 12)

Response	No. of respondents
Very easy	5
Somewhat easy	6
Somewhat difficult	1
Very difficult	0

- I thought the authoring portion was well explained. The Clear Speak can be a little difficult to decipher sometime. The number “2,” when spoken, is the hardest to understand.

Discussion

The purpose of developing ClearSpeak—including the speech rules with embedded prosody, alternative speech preferences, the ability to insert exact speech, and support for interactive navigation in Word and in browsers—was to provide SVIs with a method for accessing electronically provided math expressions using their familiar screen reader technology. The speech can be used in concert with the enlargement support in Word and browsers and the refreshable braille support provided by screen readers, such as NVDA, that support MathPlayer. This capability is an addition to the existing toolset available to SVIs and their teachers and can be used in combination with other tools or as a substitute when preferred or when other tools are unavailable.

Our goal in conducting the student and authoring pilots was to obtain information on whether the tools we developed were usable by, and helpful to, their intended audiences. Our results were positive in all cases. The student pilot found that students did as well (in some cases slightly better) in solving the math problems when using ClearSpeak (see Tables 4–6) when compared with their usual delivery format. Students generally found ClearSpeak usable (only two students said they would not want to use the spoken math if they didn’t have to), though they tended to prefer their usual methods (see Table 7). Student comments tended to be positive to enthusiastic, as noted in the Qualitative Findings section.

The teacher pilot found that teachers, including many who had never previously worked with a student who is blind or visually impaired, were successful at authoring math expressions so that the expressions would speak as directed and that they found the process somewhat to very easy.

Both for students and teachers, this pilot was their first (or in the case of repeating participants, second) exposure to the authoring and complete spoken math tools. We expect that additional use and instruction would further increase comfort levels.

Limitations

Of necessity, we worked with small sample sizes. Most of our student participants and some of the teacher participants had participated in earlier feedback studies and, so, had had an opportunity to become somewhat more familiar with the tools than someone would be on an initial encounter with them. Although we kept track of which participants were new versus repeating, sample size prevented any meaningful comparisons between repeating and new participants.

In order to be able to evaluate students' use of the spoken math tools on expressions that we knew had been authored correctly, we, rather than the participants in the authoring pilot, created the materials to be used by the students. In a fully authentic setting, the students would receive materials created by their teachers, and so any errors made by the teachers would affect the students' access to the math. An efficacy study could assess a more real-world situation, which would also be expected to include more instruction than the single authoring or navigation tutorial we provided in the pilot. Additionally, in a more authentic classroom situation, instead of implementing the speech we specified, teachers would decide how the math should be spoken, based on the instructional objectives of a given lesson. They would determine whether the default ClearSpeak rules provided the speech desired and then implement any desired speech adjustments using preferences and/or exact speech. As with students, an efficacy study for teachers would include additional instruction and practice in authoring.

Students with some usable vision were able to combine vision with spoken math for a multimodal experience. At the time of the pilot, successful integration with refreshable braille displays had not yet been confirmed. As a result, braille users in the pilot did not have access to a similar multimodal experience and relied on the speech alone. Refreshable braille devices are supported by screen readers; when the screen reader is also integrated with MathPlayer (as is the case with NVDA), attached refreshable braille devices will now display Nemeth Code for any math that can be spoken for the screen reader. That added functionality would likely further increase usability for relevant students.

Recommendations for Future Work

Because our project was focused primarily on development of tools, which were then evaluated in research, our recommendations for further work include possibilities both for additional research and for further development.

Research

In addition to an efficacy study, further work could investigate the following questions:

- How much and what types of instruction in using the authoring and speech tools are optimal for students and teachers in order to maximize effective use of the tools?
- How can the speech tools be integrated into math and assistive technology curricula for SVIs in order to improve learning outcomes?
- How usable and beneficial are the speech tools for students with disabilities other than blindness or visual impairment (e.g., learning disabilities, math-specific disabilities)? Do the tools provide any benefits to students without disabilities?
- For braille readers, would use of ClearSpeak with refreshable braille displays result in better learning outcomes than the use of either alone? Similarly, for students who use enlargement, would use of ClearSpeak with enlarged-font electronic documents result in better learning outcomes than the use of either alone? In each case, the relevant learning outcomes measured could include both math and assistive technology skills.
- For which populations, purposes, or types of math expressions are the various components (e.g., speech specification, prosody, navigation) most useful? Answers to this question might help guide priorities for future development.

Development

Development possibilities focus on enhancements and extensions. Desirable enhancements include the following:

- Further enhance and fine-tune the current set of rules and preferences. A “terse” mode, which users can select if they wish to hear a less verbose presentation, could be improved by further development.
- Enhance the interaction between navigation and exact speech set by authors.

- Investigate refreshable braille support for interactive navigation. Possibilities to be examined (and implemented if found useful) include the following:
 - Making the refreshable display change to indicate the current part being read
 - Displaying the entire (potentially large) expression, or alternatively, as much as can fit on the display, and indicating focus via dots 7 and 8 (a row of two dots, used by refreshable braille displays as a cursor, appearing below the usual three rows of two dots each in the braille cell).
- Enhance place markers so that they persist after the user exits the expression. Such an enhancement would allow users to set multiple sets of place markers in a document (enabling the user to jump around to marked locations in different expressions located in the same document) and would allow place markers to be saved along with the document.
- Enhance the Describe mode to provide more mathematically useful descriptions. This might be done either by building them into the software or by extending the authoring tools to allow authors to create the descriptions.
- Allow users to specify an automatic slowing of the speech when entering math expressions, followed by resumption of the previous speech-rate when returning to text.
- Allow authors to easily check which speech preferences are already in place when creating a new expression, and which ones they have set for a given expression (there are currently ways to check the preferences in effect for completed expressions, but they are not very easy to use).
- Allow authors to set different speech preferences for different parts of a larger expression.

Desirable extensions include the following:

- Extend the rules and preferences to address expressions used in earlier and later stages of math instruction. Our focus was secondary school algebra, which is not only foundational, but also encompasses quite a bit of territory; however, there is much more math that could be optimized for ClearSpeak, such as column arithmetic for lower grades, and calculus (and beyond) for more advanced students.
- Integrate the ClearSpeak rules and preferences, and interactive navigation, with other platforms and with additional screen readers.
- Include or reference the ClearSpeak rules and preferences in relevant accessibility standards.

Acknowledgments

We are grateful to Susan Osterhaus and Maylene Bird of the Texas School for the Blind and Visually Impaired and to Stephen L. Noble, Research Consultant at University of Louisville and Content Specialist: Mathematics and Science at Bridge MultiMedia, for their assistance with the development of the research instruments and with administering the instruments to participating students. Sina Bahram, Prime Access Consulting, was instrumental in developing the specifications for the navigation functionality. NVAccess developed the needed enhancements to the NVDA screen reader to make it work with MathPlayer, ClearSpeak, and the navigation functionality. The research reported here was supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R324A110355 to Educational Testing Service. The opinions expressed are those of the authors and do not represent views of the Institute or the U.S. Department of Education.

Notes

- 1 Some integration was also done with the Window-Eyes screen reader, but the NVDA integration is much more complete.
- 2 Documents can also be converted to Web pages, if preferred, via MathType's Publish to MathPage dialog. Such pages can also be spoken and navigated with NVDA, just as they can in Word. However, since working in Word is typically easier and more convenient for authors and readers than is posting material to a Web site, our study focused on both authoring expressions and listening to them in the Word environment.

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Appendix A

Math Instruments

This appendix shows the spoken math section followed by the 12-point version of the printed math section. The 24-point and braille versions of the print math section are not shown; they use the same content as the 12-point version.

ClearSpeak Pilot Study - Math Questions

Spoken Math Section

Type your participant ID here:

This section of the study uses the computer to speak math using MathPlayer™, the NVDA screen reader, and Microsoft Word™. Before beginning this section you should have taken the math speech and navigation tutorial. If you have not done so, please do so now, and then return to this section.

In the tutorial, you learned to do the following things:

- Play math expressions inside a Word document
- Arrow between different parts of an expression
- Zoom-in/out
- Set Place markers
- Use the “Where-am-I” command
- Toggle between the Read mode and the Describe mode
- Switch between Simple mode, character mode, and enhanced modes

Before beginning the first part of this section, please warm up by exploring the following two math expressions. After warming up, select the navigation mode (simple, character, or enhanced) that you would like to start with. You can change modes at any time, as you learned in the tutorial. (Reminder: Shift plus up or down arrow cycles through the navigation modes.)

First warm-up expression: $1 + \sqrt{2x + y} - z$

Second warm-up expression: $2(3x + 1)^2 + \frac{x + 4}{3} - 5$

Please make sure you have selected the navigation mode you want to start with (simple, enhanced, or character). Now please type the name of the mode you have selected here:

Let the study administrator know when you are ready to begin, and then continue to Part 1.

Part 1: 3 Math Questions

In Part 1 you will be asked how many zeroes there are to the right of the decimal point in 2 numbers.

Example Question for Part 1.

How many zeroes are there to the right of the decimal point in the number 3.001?

Answer: 2.

Question 1.1.

How many zeroes are there to the right of the decimal point in the number 3.0000001?

Enter your answer here:

Question 1.2.

How many zeroes are there to the right of the decimal point in the number 3.000000000001?

Enter your answer here:

This is the end of Part 1. Please save your work now by pressing Control plus S.

If you would like to take a break, please do so now, then continue on to Part 2.

Part 2: (5 Math Questions)

In Part 2 you will be asked the following five questions about a polynomial:

Question 1: How many terms does the polynomial have?

Question 2: What is the coefficient of a specific term?

Question 3: What is the coefficient of another specific term?

Question 4: What is the constant term?

Question 5: What is the degree of the polynomial? (Reminder: The degree of a polynomial is the greatest exponent.)

Here are examples.

The example Questions for Part 2 are based on the following polynomial.

$$5x^2 + 7x + 6$$

For convenience, there is a copy of the polynomial after each question.

Example Question 1.

How many terms does the polynomial have?

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 3.

Note: The 3 terms are the term $5x^2$, the term $7x$, and the term 6. (You will not be asked to name the terms, you will only be asked how many there are.)

Example Question 2.

What is the coefficient of x^2 ?

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 5.

Example Question 3.

What is the coefficient of x ?

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 7.

Example Question 4.

What is the constant term?

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 6.

Example Question 5.

What is the degree of the polynomial? (in other words, what is the greatest exponent?)

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 2.

Questions 2.1 through 2.5 are based on the following polynomial.

$$12x^6 + 18x^2 + 35x^7 + 5x^{15} + 45 + 16x^{12}$$

For convenience, there is a copy of the polynomial after each question.

Question 2.1.

How many terms does the polynomial have?

Copy of Polynomial: $12x^6 + 18x^2 + 35x^7 + 5x^{15} + 45 + 16x^{12}$

Enter your answer here:

Question 2.2

What is the coefficient of x^2 ?

Copy of Polynomial: $12x^6 + 18x^2 + 35x^7 + 5x^{15} + 45 + 16x^{12}$

Enter your answer here:

Question 2.3.

What is the coefficient of x^{12} ?

Copy of Polynomial: $12x^6 + 18x^2 + 35x^7 + 5x^{15} + 45 + 16x^{12}$

Enter your answer here:

Question 2.4.

What is the constant term?

Copy of Polynomial: $12x^6 + 18x^2 + 35x^7 + 5x^{15} + 45 + 16x^{12}$

Enter your answer here:

Question 2.5.

What is the degree of the polynomial? (In other words, what is the greatest exponent?)

Copy of Polynomial: $12x^6 + 18x^2 + 35x^7 + 5x^{15} + 45 + 16x^{12}$

Enter your answer here:

This is the end of Part 2. **Please save your work now by pressing Control plus S.**

If you would like to take a break, please do so now, then continue on to Part 3.

Part 3. (2 Math Questions)

In Part 3 you will be asked to simplify 2 math expressions by combining like terms.

Example Question for Part 3.

Simplify the expression $6x + 2 + 4x + 1$

Answer: $10x + 3$.

Note: The answer was entered using the keyboard. The “plus” in the answer was entered using the plus sign (Shift + =). It could also have been entered using the word “plus.”

Question 3.1.

Simplify the expression. $3x + 2 + 6x + 8 + 4x$.

Enter your answer here:

Question 3.2.

Simplify the expression $6 + 2y - 4 + 7x - 4y - 2x + 5 - 4x + 10y$

Enter your answer here:

This is the end of Part 3. **Please save your work now by pressing Control plus S.**

If you would like to take a break, please do so now, then continue on to Part 4.

Part 4: 3 Math Questions

In Part 4 you will be asked to calculate the value of 3 numerical expressions.

When you are calculating the value of an expression, remember to evaluate it using the rules for order of operations. In case you’ve forgotten what the rules for order of operations are, here they are.

Operations should be performed in the following order

1. Parentheses
2. Exponents
3. Multiplication and Division (from left to right)
4. Addition and Subtraction (from left to right)

Some students remember the order of operations rule by using the mnemonic PEMDAS.

Example Question for Part 4.

What is the value of the numerical expression $4(3 + 2)$?

Answer: 20.

Question 4.1.

What is the value of the numerical expression $2(3 + 1) + 4(3 + 2)$?

Enter the value of the expression here:

Question 4.2.

What is the value of the expression $2(2 + 3)^2(4 - 2)^3$?

Enter the value of the expression here:

Question 4.3.

What is the value of the expression $2((3 + 7) - (6 - 4)) - 3$?

Enter the value of the expression here:

This is the end of Part 4. **Please save your work now by pressing Control plus S.**

If you would like to take a break, please do so now, then continue on to Part 5.

Part 5: 2 Math Questions

In Part 5 you will be asked to simplify algebraic fractions.

The numerator and the denominator of each algebraic fraction will each be the product of several expressions. (That is, the numerator is several expressions multiplied together. So is the denominator.)

Fractions like these are simplified by canceling as shown in the following two examples.

Example Algebraic Fraction 1: $\frac{(x + 1)(x + 2)}{(x + 1)(x + 4)}$.

The numerator is the product of two expressions: the expression $(x + 1)$ and the expression $(x + 2)$.

The denominator is the product of two expressions: the expression $(x + 1)$ and the expression $(x + 4)$.

The $(x + 1)$ in the numerator and $(x + 1)$ in the denominator cancel out, leaving $(x + 2)$ in the numerator and $(x + 4)$ in the denominator. No further cancellation is possible, so the simplified fraction is $\frac{(x + 2)}{(x + 4)}$.

Example Algebraic Fraction 2: $\frac{(x + 1)(x + 2)(x + 2)}{(x + 2)(x + 4)}$.

The numerator is the product of three expressions: the expression $(x + 1)$, the expression $(x + 2)$, and the expression $(x + 2)$ again.

The denominator is the product of two expressions: the expression $(x + 2)$, and the expression $(x + 4)$.

One of the two instances of $(x + 2)$ in the numerator and the one instance of $(x + 2)$ in the denominator cancel out, leaving the two expressions $(x + 1)$ and $(x + 2)$ in the numerator, and the expression $(x + 4)$ in the denominator. No further cancellation is possible, so the simplified fraction is $\frac{(x + 1)(x + 2)}{(x + 4)}$.

You will enter your answer to these questions using the keyboard. The following shows how you would enter the simplified fraction $\frac{(x + 1)(x + 2)}{(x + 4)}$.

Answer.

Enter the numerator of the simplified fraction here: $(x + 1)$ times $(x + 2)$

(Entering the numerator as $(x + 1)(x + 2)$ is also correct.)

Note that in both ways of entering the answer there are parentheses around the expression $x + 1$ and around the expression $x + 2$. The presence of these parentheses clearly indicates that the answer is the product of two expressions: the expression $x + 1$, and the expression $x + 2$. When you enter answers that are the product of two or more expressions, make sure to put parentheses around each of the expressions being multiplied together.

To enter an open parenthesis press **Shift + 9** and to enter a close parenthesis press **Shift + 0**. A hyphen is used to represent a minus sign. On the keyboard, the hyphen is the key immediately to the right of the 0 key. To enter the plus sign type **Shift + =**.

Enter the denominator of the simplified fraction here: $(x + 4)$

Note that, the answer is entered with parentheses surrounding the expression $x + 4$. In fact, since the expression $x + 4$ is not being multiplied by another expression, it would have been equally correct, and clear, to enter the expression without the surrounding parentheses.

Question 5.1.

Simplify the algebraic fraction $\frac{(x+1)(2x-3)}{(2x+1)(x+1)(2x+3)}$.

Enter the numerator of the simplified fraction here:

Enter the denominator of the simplified fraction here:

Question 5.2.

Simplify the algebraic fraction $\frac{(x+1)(2x+3)(3x-2)}{(2x+3)(3x-2)(3x-2)}$

Enter the numerator of the simplified fraction here:

Enter the denominator of the simplified fraction here:

This is the end of Part 5. Please save your work now by pressing Control plus S.

If you would like to take a break, please do so now, then continue on to part 6.

Part 6: 2 Math Questions

In Part 6 you will be given 3 exponential expressions, which can be simplified using the following rule.

Rule: $\frac{r^s}{r^t} = r^{s-t}$

So for example $\frac{2^{10}}{2^6} = 2^{10-6} = 2^4$ and $\frac{4^6 \cdot x^5}{4^9 \cdot x^3} = 4^{6-9} \cdot x^{5-3} = 4^{-3} \cdot x^2$

For each of the 2 exponential expressions in this part you will be asked to choose from a list of possibilities, which is the correct simplification.

Question 6.1.

The expression $\frac{3^{12}}{3^4}$ simplifies to

- A. 3^{-16}
- B. 3^{-8}
- C. 3^{-3}
- D. 3^3
- E. 3^8
- F. 3^{16}

Enter your answer here:

Question 6.2.

This expression $\frac{x^9 \cdot y^5 \cdot z^{-7}}{y^2 \cdot z^{-3}}$ simplifies to

- A. $x^7 \cdot y^3 \cdot z^{-4}$
- B. $x^9 \cdot y^3 \cdot z^{-10}$
- C. $x^9 \cdot y^3 \cdot z^{-4}$
- D. $x^9 \cdot y^7 \cdot z^{-4}$

Enter your answer here:

This is the end of Part 6. Please save your work now by pressing Control plus S.

Please let the study administrator know that you have finished this part. Then answer the following 5 questions about navigation modes.

Navigation Question 1.

After you set your starting navigation mode, how often did you switch modes?

- A. Very often
- B. A few times
- C. Once or twice
- D. Never (used the same mode all the way through)

Enter your answer here:

Navigation Question 2.

How often did you use Simple mode?

- A. Always or almost always
- B. Often
- C. Sometimes
- D. Rarely or never

Enter your answer here:

Navigation Question 3.

How often did you use Enhanced mode?

- A. Always or almost always
- B. Often
- C. Sometimes
- D. Rarely or never

Enter your answer here:

Navigation Question 4.

How often did you use Character mode?

- A. Always or almost always
- B. Often
- C. Sometimes
- D. Rarely or never

Enter your answer here:

Navigation Question 5.

Of the three navigation modes, which is your favorite? (If you liked two of the modes much more than the other one, indicate the two you liked best.)

- A. No favorite - like them all about the same
- B. Simple mode
- C. Enhanced mode
- D. Character mode

Enter your answer here:

This is the end of the math questions in the Spoken Math section. If you would like to take a break please do so, and then continue to the feedback questions for the Spoken Math section.

ClearSpeak Pilot Study - Math Questions

Regular Print Format Section

Enter your participant ID here:

In this section of the study you will be asked math questions in a format you usually use. If you have been given a format that is *not* something you usually use, please ask the study administrator for the correct format. If you cannot enter the answers yourself, your scribe may enter them for you.

Let the study administrator know when you are ready to begin, and then continue to Part 1.

Part 1: 3 Math Questions

In Part 1 you will be asked how many zeroes there are to the right of the decimal point in 2 numbers.

Example Question for Part 1.

How many zeroes are there to the right of the decimal point in the number 3.001 ?

Answer: 2.

Question 1.1.

How many zeroes are there to the right of the decimal point in the number 3.000001 ?

Enter your answer here:

Question 1.2.

How many zeroes are there to the right of the decimal point in the number 3.00000000000001 ?

Enter your answer here:

This is the end of Part 1. If you would like to take a break, please do so now, then continue on to Part 2.

Part 2: (5 Math Questions)

In Part 2 you will be asked the following five questions about a polynomial:

Question 1: How many terms does the polynomial have?

Question 2: What is the coefficient of a specific term?

Question 3: What is the coefficient of another specific term?

Question 4: What is the constant term?

Question 5: What is the degree of the polynomial? (Reminder: The degree of a polynomial is the greatest exponent.)

The example Questions for Part 2 are based on the following polynomial.

$$5x^2 + 7x + 6$$

For convenience, there is a copy of the polynomial after each question.

Example Question 1.

How many terms does the polynomial have?

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 3.

Note: The 3 terms are: the term $5x^2$, the term $7x$, and the term 6. (You will not be asked to name the terms, you will only be asked how many there are.)

Example Question 2.

What is the coefficient of x^2 ?

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 5.

Example Question 3.

What is the coefficient of x ?

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 7.

Example Question 4.

What is the constant term?

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 6.

Example Question 5.

What is the degree of the polynomial? (in other words, what is the greatest exponent?)

Copy of Polynomial: $5x^2 + 7x + 6$

Answer: 2.

Questions 2.1 through 2.5 are based on the following polynomial.

$$8x^9 + 22x^{17} + 16x^2 + 56 + 5x^{14} + 33x + 18x^{11}$$

For convenience, there is a copy of the polynomial after each question.

Question 2.1.

How many terms does the polynomial have?

Copy of Polynomial $8x^9 + 22x^{17} + 16x^2 + 56 + 5x^{14} + 33x + 18x^{11}$

Enter your answer here:

Question 2.2

What is the coefficient of x^2 ?

Copy of Polynomial: $8x^9 + 22x^{17} + 16x^2 + 56 + 5x^{14} + 33x + 18x^{11}$

Enter your answer here:

Question 2.3.

What is the coefficient of x^{11} ?

Copy of Polynomial: $8x^9 + 22x^{17} + 16x^2 + 56 + 5x^{14} + 33x + 18x^{11}$

Enter your answer here:

Question 2.4.

What is the constant term?

Copy of Polynomial: $8x^9 + 22x^{17} + 16x^2 + 56 + 5x^{14} + 33x + 18x^{11}$

Enter your answer here:

Question 2.5.

What is the degree of the polynomial? (In other words, what is the greatest exponent?)

Copy of Polynomial: $8x^9 + 22x^{17} + 16x^2 + 56 + 5x^{14} + 33x + 18x^{11}$

Enter your answer here:

This is the end of Part 2.

If you would like to take a break, please do so now, then continue on to Part 3.

Part 3. (2 Math Questions)

In Part 3 you will be asked to simplify 2 math expressions by combining like terms.

Example Question for Part 3.

Simplify the expression $6x + 2 + 4x + 1$

Answer: $10x + 3$.

Question 3.1.

Simplify the expression. $2 + 4y + 7 + 5y + 3y$.

Enter your answer here:

Question 3.2.

Simplify the expression $4 + 3x - 2 + 8y - 2x - 3y + 5 - 4y + 10x$

Enter your answer here:

This is the end of Part 3.

If you would like to take a break, please do so now, then continue on to Part 4

Part 4: 3 Math Questions

In Part 4 you will be asked to calculate the value of 3 numerical expressions.

When you are calculating the value of an expression, remember to evaluate it using the rules for order of operations.

In case you've forgotten what the rules for order of operations are, here they are.

Operations should be performed in the following order:

1. Parentheses
2. Exponents
3. Multiplication and Division (from left to right)
4. Addition and Subtraction (from left to right)

Some students remember the order of operations rule by using the mnemonic PEMDAS.

Example Question for Part 4.

What is the value of the numerical expression $4(3 + 2)$?

Answer: 20.

Question 4.1.

What is the value of the numerical expression $2(4 + 1) + 4(1 + 2)$?

Enter the value of the expression here:

Question 4.2.

What is the value of the expression $4(4 + 1)^2(5 - 3)^3$?

Enter the value of the expression here:

Question 4.3.

What is the value of the expression $3((6 + 5) - (8 - 4)) - 2$?

Enter the value of the expression here:

This is the end of Part 4.

If you would like to take a break, please do so now, then continue on to Part 5.

Part 5: 2 Math Questions

In Part 5 you will be asked to simplify algebraic fractions.

The numerator and the denominator of each algebraic fraction will each be the product of several expressions. (That is, the numerator is several expressions multiplied together. So is the denominator.)

Fractions like these are simplified by canceling as shown in the following two examples.

Example Algebraic Fraction 1. $\frac{(x + 1)(x + 2)}{(x + 1)(x + 4)}$.

The numerator is the product of two expressions: the expression $(x + 1)$ and the expression $(x + 2)$.

The denominator is the product of two expressions: the expression $(x + 1)$ and the expression $(x + 4)$.

The $(x + 1)$ in the numerator and $(x + 1)$ in the denominator cancel out, leaving $(x + 2)$ in the numerator and $(x + 4)$

in the denominator. No further cancellation is possible, so the simplified fraction is $\frac{(x + 2)}{(x + 4)}$.

Example Algebraic Fraction 2. $\frac{(x + 1)(x + 2)(x + 2)}{(x + 2)(x + 4)}$.

The numerator is the product of three expressions: the expression $(x + 1)$, the expression $(x + 2)$, and the expression $(x + 2)$ again.

The denominator is the product of two expressions: the expression $(x + 2)$, and the expression $(x + 4)$.

One of the two instances of $(x + 2)$ in the numerator and the one instance of $(x + 2)$ in the denominator cancel out, leaving the two expressions $(x + 1)$ and $(x + 2)$ in the numerator, and the expression $(x + 4)$ in the denominator. No further

cancellation is possible, so the simplified fraction is $\frac{(x + 1)(x + 2)}{(x + 4)}$.

The following shows how you would enter the simplified fraction $\frac{(x + 1)(x + 2)}{(x + 4)}$ in the answer space provided.

Answer.

Enter the numerator of the simplified fraction here: $(x + 1)(x + 2)$

Enter the denominator of the simplified fraction here: $(x + 4)$

Note that in the numerator there are parentheses around the expression $x + 1$ and around the expression $x + 2$. The presence of these parentheses clearly indicates that the answer is the product of two expressions: the expression $x + 1$, and the expression $x + 2$. When you enter numerators or denominators that are the product of two or more expressions, make sure to put parentheses around each of the expressions being multiplied together.

Also note that, in the denominator there are parentheses surrounding the expression $x + 4$. In fact, since the expression $x + 4$ is not being multiplied by another expression, it would have been equally correct, and clear, to enter the expression $x + 4$ without the surrounding parentheses.

Question 5.1.

Simplify the Algebraic Fraction $\frac{(x+2)(3x+2)}{(x+2)(2x+1)(3x-2)}$

Answer

Enter the numerator of the simplified fraction here:

Enter the denominator of the simplified fraction here:

Question 5.2.

Simplify the Algebraic Fraction $\frac{(x+1)(2x+3)(3x+2)}{(2x+3)(x-1)(3x+2)}$

Answer

Enter the numerator of the simplified fraction here.

Enter the denominator of the simplified fraction here.

This is the end of Part 5.

If you would like to take a break, please do so now, then continue on to Part 6.

Part 6: 2 Math Questions

In Part 6 you will be given 3 exponential expressions, which can be simplified using the following rule.

$$\text{Rule: } \frac{r^s}{r^t} = r^{s-t}$$

$$\text{So for example } \frac{2^{10}}{2^6} = 2^{10-6} = 2^4 \text{ and } \frac{4^6 \cdot x^5}{4^9 \cdot x^3} = 4^{6-9} \cdot x^{5-3} = 4^{-3} \cdot x^2$$

For each of the two exponential expressions in this part you will be asked to choose from a list of possibilities, which is the correct simplification.

Question 6.1.

The expression $\frac{5^{16}}{5^4}$ simplifies to

- A. 5^{-20}
- B. 5^{-12}
- C. 5^{-4}
- D. 5^4
- E. 5^{12}
- F. 5^{20}

Enter your answer here:

Question 6.2.

This expression $\frac{x^8 \cdot y^6 \cdot z^{-9}}{y^4 \cdot z^{-2}}$ simplifies to

- A. $x^4 \cdot y^2 \cdot z^{-7}$
- B. $x^8 \cdot y^2 \cdot z^{-11}$
- C. $x^8 \cdot y^2 \cdot z^{-7}$
- D. $x^8 \cdot y^{10} \cdot z^{-7}$

Enter your answer here:

This is the end of Part 6.

This is the end of the math questions in the Print Format section. Please let the study administrator know when you have finished this section.

Appendix B

Feedback Instruments

The following materials are included in this appendix in the order shown:

- Spoken math feedback
- Printed math feedback
- Braille math feedback
- End-of-session (“After Both Math Sections”) feedback (for students)
- Authoring feedback

Feedback: Spoken Math Section

11 Questions

Press the down-arrow key twice, then type your participant ID below:

If you made any notes while taking the tutorial or while answering the questions in the spoken math section, please refer to those notes if they would help you answer these feedback questions.

Question 1.

Whether or not you knew how to solve all of the math problems, overall, how easy was it to understand what the math expressions in the spoken math section were?

- A. Very easy
- B. Somewhat easy
- C. Somewhat hard
- D. Very hard

Press the down-arrow key twice, then type your answer to Question 1.

Question 2.

What about the way the math was presented in the spoken math section made them easy or hard to work with? If you have any suggestions for improvement, please include those with your answer.

Press the down-arrow key twice, then type your answer to Question 2.

Question 3.

In answering the math questions in the spoken math section, how often did you write down the expressions (in braille, on paper, on the computer, etc.) or ask your scribe to do so?

- A. Always
- B. All except the easiest ones
- C. Only the hardest ones
- D. Never

Press the down-arrow key twice, then type your answer to Question 3.

Questions 4–9 are about the spoken math tools.

In the spoken math tutorial you learned how to

- Arrow between different parts of an expression
- Zoom-in/out
- Set and Return to Place markers
- Use the Where am I command

- Toggle between the Read mode and the Describe mode
- Switch between Simple mode, Character mode, and Enhanced mode

We would like your feedback on the things you learned how to do in the tutorial, on the tutorial itself, and on how you used the tools to answer the questions in the spoken math section.

Question 4.

Which best describes your opinion of the tools for arrowing back and forth in spoken math expressions?

- A. Using them made the spoken math much easier to understand.
- B. Using them made the spoken math somewhat easier to understand.
- C. Using them made the spoken math slightly easier to understand.
- D. Using them did not make the spoken math any easier to understand.

Press the down-arrow key twice, then type your answer to Question 4.

Press the down-arrow key twice, then type any comments about things you liked or didn't like about the arrowing tools or about how the tutorial explained the arrowing tools.

Question 5.

Which best describes your opinion of the tools for Zoom-in and zoom out in spoken math expressions?

- A. Using them made the spoken math much easier to understand.
- B. Using them made the spoken math somewhat easier to understand.
- C. Using them made the spoken math slightly easier to understand.
- D. Using them did not make the spoken math any easier to understand.

Press the down-arrow key twice, then type your answer to Question 5.

Press the down-arrow key twice, then type any comments about things you liked or didn't like about the zooming tools or about how the tutorial explained the zooming tools.

Please save your work now by pressing Control plus S.

Questions 6–9 are about tools that you might use for some spoken math expressions but not for others. You might decide to use them only for longer or more complicated expressions. Please answer these questions with those types of math expressions in mind.

Question 6.

Which best describes your opinion of the tools for setting and returning to place markers in spoken math expressions?

- A. Using them made complicated or long spoken math expressions much easier to work with.
- B. Using them made complicated or long spoken math expressions somewhat easier to work with.
- C. Using them made complicated or long spoken math expression slightly easier to work with.
- D. Using them did not make complicated or long spoken math expression any easier to work with.

Press the down-arrow key twice, then type your answer to Question 6.

Press the down-arrow key twice, then type any comments about things you liked or didn't like about the place marker tools or about how the tutorial explained the place marker tools.

Question 7.

Which best describes your opinion of the Where am I tools in spoken math expressions?

- A. Using them made complicated or long spoken math expressions much easier to work with.
- B. Using them made complicated or long spoken math expressions somewhat easier to work with.

- C. Using them made complicated or long spoken math expression slightly easier to work with.
- D. Using them did not make complicated or long spoken math expression any easier to work with.

Press the down-arrow key twice, then type your answer to Question 7.

Press the down-arrow key twice, then type any comments about things you liked or didn't like about the Where am I tools or about how the tutorial explained the Where am I tools.

Question 8.

Which best describes your opinion of the tools for toggling between Read mode and Describe mode in spoken math expressions?

- A. Using them made complicated or long spoken math expressions much easier to work with.
- B. Using them made complicated or long spoken math expressions somewhat easier to work with.
- C. Using them made complicated or long spoken math expression slightly easier to work with.
- D. Using them did not make complicated or long spoken math expression any easier to work with.

Press the down-arrow key twice, then type your answer to Question 8.

Press the down-arrow key twice, then type any comments about things you liked or didn't like about the tools for toggling between Read mode and Describe mode or about how the tutorial explained the tools for toggling between Read mode and Describe mode.

Question 9.

Which best describes your opinion of the simple, enhanced, and character modes and the tools for switching between those modes in spoken math expressions?

- A. Using them made complicated or long spoken math expressions much easier to work with.
- B. Using them made complicated or long spoken math expressions somewhat easier to work with.
- C. Using them made complicated or long spoken math expression slightly easier to work with.
- D. Using them did not make complicated or long spoken math expression any easier to work with.

Press the down-arrow key twice, then type your answer to Question 9.

Press the down-arrow key twice, then type any comments about things you liked or didn't like about the Simple, Enhanced, and Character modes and the tools for switching between those modes or about how the tutorial explained those modes and related tools.

If you participated in any of the previous studies for this project (as described in the background survey), please answer questions 10 and 11. Otherwise, please save your work now by pressing Control plus S, and then let your study administrator know that you are finished with these questions.

Question 10.

Please enter any comments you have about how the spoken math has changed compared to the way it worked in the previous study or studies you participated in.

Press the down-arrow key twice, then type your answer to Question 10.

Question 11.

Now that you have used the spoken math some more, have your opinions about any aspects of it changed since the previous studies you participated in? If so, please describe how your opinions have changed, including which aspects of the spoken math you think differently about.

Press the down-arrow key twice, then type your answer to Question 11.

Please save your work now by pressing Control plus S.

This is the end of the spoken math feedback questions. Please let your study administrator know that you are finished with these questions.

Feedback: Print Section

4 Questions

Enter your participant ID below:

If you made any notes while answering the questions in the print section, please refer to those notes if they would help you answer these feedback questions.

Question 1

Whether or not you knew how to solve all of the math problems, overall, how easy was it to understand what the math expressions in the print section were?

- A. Very easy
- B. Somewhat easy
- C. Somewhat hard
- D. Very hard

Enter your answer to Question 1 in the space below.

Question 2

What about the way the math was presented in the print section made them easy or hard to work with? If you have any suggestions for improvement, please include those with your answer.

Enter your answer to Question 2 in the space below.

Question 3

The typeface and size (e.g., Arial 12) are indicated in the print sections. Please indicate which typeface and size you used. (If you and your scribe used different sizes, be sure to indicate the size that you used.)

Enter your answer to Question 3 in the space below.

Question 4

Did you use any type of magnification (e.g., CCTV, hand-held magnifier, ZoomText, etc.) with the print section? If so, please describe what you used:

Enter your answer to Question 4 in the space below.

Feedback: Braille Section

3 Questions

Enter your participant ID below:

If you made any notes while answering the questions in the braille section, please refer to those notes if they would help you answer these feedback questions.

Question 1

Whether or not you knew how to solve all of the math problems, overall, how easy was it to understand what the math expressions in the braille section were?

- A. Very easy
- B. Somewhat easy
- C. Somewhat hard
- D. Very hard

Indicate your answer to Question 1.

Question 2

What about the way the math was presented in the braille section made them easy or hard to work with? If you have any suggestions for improvement, please include those with your answer.

Indicate your answer to Question 2.

Question 3

In answering the math questions in the braille section, how often did you write down the expressions (in braille, on paper, on the computer, etc.) or ask your scribe to do so?

- A. Always
- B. All except the easiest ones
- C. Only the hardest ones
- D. Never

Indicate your answer to Question 3.

Feedback: After Both Math Sections

Press the down-arrow key twice, then enter your participant ID below:

If you made any notes while taking the tutorial or while answering the questions in either of the math sections, please refer to those notes if they would help you answer these feedback questions.

You have now worked with several similar math problems presented in two different ways. This set of feedback questions asks you to make comparisons between the two sections: the spoken math section and a section in your usual format.

Question 1

Overall, which statement best describes your opinion of the two sections?

- A. I would always prefer my usual method, and would not want to use the spoken math if I didn't have to.
- B. I would usually or always prefer my usual method, but the spoken math is ok.
- C. I prefer them about equally, and it might depend on the type of math or situation which one I would prefer at a particular time. (If you choose this answer, please also describe what situations would lead you to preferring the spoken math format, and what situations would lead you to prefer your usual format).
- D. I would usually or always prefer the spoken math but my usual method is ok
- E. I would always prefer the spoken math, and would not want to go back to using my usual method if I didn't have to.
- F. I would sometimes like to use my usual method and the spoken math together.
- G. I would always like to use both my usual method and the spoken math together.

Press the down-arrow key twice, then type your answer to Question 1.

Question 2

You worked math questions in two sections. One was in spoken math, the other in print or braille. Which best describes how long it took to work on the math questions in the two sections? When thinking about the time each section took, do not count time spent on the tutorials or any feedback questions after the math questions.

- A. The spoken math section took much less time than the other section.
- B. The spoken math section took a little less time than the other section.
- C. Both sections took about the same amount of time.
- D. The spoken math section took a little more time than the other section.
- E. The spoken math section took much more time than the other section.

Press the down-arrow key twice, then type your answer to Question 2.

Question 3

Which best describes how confident you felt about working on the math questions in the two sections?

- A. Much more confident in the section in my usual format
- B. A little more confident in the section in my usual format
- C. About the same
- D. A little more confident in the spoken math section
- E. Much more confident in the spoken math section

Press the down-arrow key twice, then type your answer to Question 3.

Expanding Audio Access to Mathematics Expressions by Students with Visual Impairments via MathML

Pilot Authoring Feedback Instrument

Estimated time: 30 minutes.

Please save this instrument under the name PilotAuthoringFeedback-xx.doc, replacing the “xx” with your participant ID code. For example if your id code is “06” the file should be named PilotAuthoringFeedback-06.doc. Also, please write your participant ID here:

ID: _____

1. How easy or difficult did you find the tasks in the Pilot Authoring Assessment Instrument?

- A. Very easy
- B. Somewhat easy
- C. Somewhat difficult
- D. Very difficult

Response: _____

2. When performing the authoring tasks, how much did you refer back to the tutorial?

- A. For each of the expressions authored.
- B. For some of the expressions authored
- C. Only when something didn't work as expected
- D. Not at all

Response: _____

3. When authoring the expressions, how much did you refer back to the reference document *ClearSpeak Rules and Preferences Excerpt*?

- A. For each of the expressions authored.
- B. For some of the expressions authored
- C. Only when something didn't work as expected
- D. Not at all

Response: _____

4. Please add any comments on ways the tutorial or the reference document could be improved to make the authoring tasks easier. If there are expressions that you found particularly difficult, to author as indicated in the instrument, please describe them. Type your response below:

5. Overall, how helpful did you find the tutorial in preparing you for the authoring tasks?

- A. Very helpful
- B. Somewhat helpful
- C. Somewhat unhelpful
- D. Not at all helpful

Response: _____

6. Especially if your answer to question 5 was “Somewhat unhelpful” or “not at all helpful,” can you provide suggestions for improvement? Please enter your comments below:

7. We are considering creating videos to go over each section of the tutorial. Which best describes your feeling about using videos, compared with the written tutorial?

- A. I would use the written tutorial exclusively.
- B. I would use both, but mostly the written tutorial.
- C. I would use both approximately equally.
- D. I would use both, but mostly the video tutorial.
- E. I would use the video tutorial exclusively.

Response: _____

8. For either a written or video tutorial, are there instructions or techniques that you would like to see added, removed, or covered in more or less detail? If so, please enter your comments below:
9. If you have any thoughts on how the authoring functionality itself might be improved, please enter them below.
10. If you participated in the authoring feedback study late in 2014, please enter any comments on differences you perceived in clarity or ease of use between the earlier and later versions of the tutorial and reference documents. Please note if you feel that having done similar tasks in the previous study made the tasks easier this time. Please enter the comments below, or enter “n/a” if you did not participate in the previous study.

Thanks for your feedback! Please save this document before exiting.

Appendix C

Background Surveys

The following materials are included in this appendix in the order shown:

- Student background survey
- Student background survey for teachers
- Authoring background survey

Background Questions for Students

ID Number: _____

Current or most recent math class taken: _____

Current grade in school: _____

Age: _____

Please answer the following questions about your experience using various methods to read math problems:

1. My best (most preferred) method for reading math materials, including math problems is (select one):
 - a. Having someone read them to me
 - b. Listening to them being read on tape, CD, MP3, etc.
 - c. Having a computer read them to me
 - d. Reading them from hard-copy (paper) braille, in Nemeth Code
 - e. Reading them from hard-copy (paper) braille, but not using Nemeth Code
 - f. Reading them in braille using a refreshable braille display on a computer or note taker
 - g. Reading them in large print on paper
 - h. Reading them using screen enlargement on the computer
 - i. Reading them using a CCTV or similar device
 - j. Something else (describe)
2. My usual method (not necessarily best or most preferred method) for reading math materials, including math problems is (select one):
 - a. Having someone read them to me
 - b. Listening to them being read on tape, CD, MP3, etc.
 - c. Having a computer read them to me
 - d. Reading them from hard-copy (paper) braille, in Nemeth Code
 - e. Reading them from hard-copy (paper) braille, but not using Nemeth Code
 - f. Reading them in braille using a refreshable braille display on a computer or note taker
 - g. Reading them in large print on paper
 - h. Reading them using screen enlargement on the computer
 - i. Reading them using a CCTV or similar device
 - j. Something else (describe)
3. If your best method is not the same as your usual method, please explain why that is.

Enter your answer here:

4. Which best describes how convenient it is for you to obtain math materials in formats that work with your best method for reading them? For example, if your best method is braille or large print, how convenient is it for you to obtain those materials? If your best method involves screen enlargement on the computer, how convenient is it for you to get access to a computer with that software? If your best method is having a computer read them to you, how convenient is it for you to obtain the materials in a format a computer can read, and get access to a computer with a screenreader? If your best method involves having someone read it to you, how convenient is it to arrange to meet with your reader when you need to?
- Very convenient
 - Somewhat convenient
 - Somewhat inconvenient
 - Very inconvenient

If you answered somewhat inconvenient or very inconvenient, describe the ways in which it is inconvenient or the types of materials that are inconvenient to obtain in your best method.

Enter your answer here:

5. In addition to text, most math materials contain mathematical expressions. It is important that you understand what each of these mathematical expressions is before you begin to work with it. Which best describes how well mathematical expressions are presented in the method you usually use to read math materials?
- Very well. I can always, or almost always tell what the math expression is.
 - Well. I can usually tell what the math expression is.
 - Not well. I often have trouble telling what the math expression is.
 - Awful. I usually can't tell what the math expression is.
6. Which best describes how easy or difficult it was to learn to work with your usual format (when you first started working with that format)?
- Very easy
 - Somewhat easy
 - Somewhat difficult
 - Very difficult

If you answered somewhat difficult or very difficult, describe what made it difficult.

Enter your answer here:

Now that you have told us about your best method and your usual method, we want to understand what experience, if any, you have with all the methods listed.

7. Which best describes your experience with having someone read math to you? Select all that apply:
- I haven't used it
 - I am learning to use it
 - I have used it, but it is confusing
 - I have used it, and it is helpful
8. Which best describes your experience with listening to prerecorded math being read on tape, CD, MP3, etc.? Select all that apply:
- I haven't used it
 - I am learning to use it
 - I have used it, but it is confusing
 - I have used it, and it is helpful
9. Which best describes your experience with having a computer read math to you (that is, the speech is generated by the computer, not prerecorded)? Select all that apply:

- a. I haven't used it
 - b. I am learning to use it
 - c. I have used it, but it is confusing
 - d. I have used it, and it is helpful
10. Which best describes your experience with reading math from hard-copy (paper) braille, using Nemeth Code? Select all that apply:
- a. I haven't used it
 - b. I don't read the Nemeth code well enough to use it
 - c. I am learning to use it
 - d. I have used it, but it is confusing
 - e. I have used it, and it is helpful
11. Which best describes your experience with reading math from hard-copy (paper) braille, but not using Nemeth Code? Select all that apply:
- a. I haven't used it
 - b. I am learning to use it
 - c. I have used it, but it is confusing
 - d. I have used it, and it is helpful
12. Which best describes your experience with reading math braille using a refreshable braille display on a computer or note taker? Select all that apply:
- a. I haven't used it
 - b. I don't read the braille math code well enough to use it
 - c. I am learning to use it
 - d. I have used it, but it is confusing
 - e. I have used it, and it is helpful
13. Which best describes your experience with reading math in large print on paper? Select all that apply:
- a. I haven't used it
 - b. I don't see well enough to use it
 - c. I am learning to use it
 - d. I have used it, but it is confusing
 - e. I have used it, and it is helpful
14. Which best describes your experience with reading math using screen enlargement on the computer? Select all that apply:
- a. I haven't used it
 - b. I don't see well enough to use it
 - c. I am learning to use it
 - d. I have used it, but it is confusing
 - e. I have used it, and it is helpful
15. Which best describes your experience with reading math using screen enlargement on a CCTV or similar device? Select all that apply:
- a. I haven't used it
 - b. I don't see well enough to use it
 - c. I am learning to use it
 - d. I have used it, but it is confusing
 - e. I have used it, and it is helpful
16. Which best describes how you use or do not use vision for math?

- a. I usually or always use vision by itself if the math is displayed in a way I can use (with enlargement, the right font, the right color paper or screen display, etc.).
 - b. I usually or always use some combination of vision and other methods (braille, recordings, other assistive technology) to work with math.
 - c. I usually or always use nonvisual methods (braille, recordings, other assistive technology) to work with math.
17. Which best describes how you use computer screen readers (such as JAWS, NVDA, Window-Eyes, VoiceOver, etc.) for school work or homework, other than math or science?
- a. I have never used a screen reader.
 - b. I use screen readers sometimes, but only when I can't get material in a format I prefer (such as braille or large print).
 - c. I use and like screen readers about as much as other formats, such as braille or large print.
 - d. I use screen readers and prefer them to material in other formats, such as braille or large print.
18. If you sometimes or often use a screen reader, please tell us about what things you like most about using a screen reader, and what types of things for which you prefer a screen reader over other ways of reading it. For example, think if different activities and different kinds of subject matter.

Enter your answer here:

19. If you have ever used a screen reader, whether or not you currently use one or like using one, please tell us about what things you like least about using a screen reader, and what types of things for which you prefer some other way of reading it instead of a screen reader. For example, think if different activities and different kinds of subject matter.

Enter your answer here:

20. Which of these screen readers have you used? Mark all that apply.

- a. JAWS
- b. NVDA
- c. Window-Eyes
- d. VoiceOver
- e. ZoomText with Speech
- f. Other (describe)
- g. Never used a screen reader

21. In this study, you will have an opportunity to read math using a screen reader. Before you try that out, we would like to know what you think a screen reader should be able to do with math. Think about how it would speak the math and allow you to move around inside (that is, navigate) the math.

Enter your answer here:

22. We have conducted some earlier studies for this project. Please read the descriptions and mark which ones, if any, you participated in, or think you might have participated in:

Study A.

In the spring of 2012, we conducted a study where students listened to prerecorded computer speech. You might have used an MP3 player to listen to it, or may have used a media player on the computer. In that study, students were asked to answer math questions where the computer spoke the math in three different ways, and then let us know which ways of speaking the math were easiest to understand.

Study B.

In the spring of 2013, we conducted a study where students listened to the Window-Eyes screen reader reading math in Microsoft Word files. We asked questions like, "How helpful for telling what was under the square root were the wording and the way it was paced?"

Study C

At the end of 2014 or the beginning of 2015, we conducted a study where students went through a tutorial on navigating math expressions using the NVDA screen reader, and then answered feedback questions about the tutorial and the methods taught for using arrow keys, zooming in and out, and using place markers.

Which of these studies did you participate in or think you may have participated in? Mark all that apply:

Study A

Study B

Study C

None of them

Finally, we would like to know a bit about your math background.

23. Please rate your skill at working with fractions in algebra problems.
 - a. I'm just learning
 - b. I'm pretty good at it
 - c. I'm an expert
24. Please rate your skill at working with square roots in algebra problems.
 - a. I'm just learning
 - b. I'm pretty good at it
 - c. I'm an expert
25. Please rate your skill at working with math statements using parentheses in algebra problems.
 - a. I'm just learning
 - b. I'm pretty good at it
 - c. I'm an expert

Student Background Questions for Teachers

Student's ID Number: _____

Please answer the following questions to the best of your knowledge of how this student accesses math. If you do not know the answer to a given question, please leave it blank.

7. The student's best (most preferred) method for working on math problems is (select one):
 - a. Having someone read them aloud
 - b. Listening to them being read on tape, CD, MP3, etc.
 - c. Using a computer with text-to-speech
 - d. Reading them from hard-copy (paper) braille, in Nemeth Code
 - e. Reading them from hard-copy (paper) braille, but not using Nemeth Code
 - f. Reading them in braille using a refreshable braille display on a computer or note taker
 - g. Reading them in large print on paper
 - h. Reading them using screen enlargement on the computer
 - i. Reading them using a CCTV or similar device
 - j. Something else (describe)
8. The student's usual method (not necessarily best or most preferred method) for reading math materials, including math problems is (select one):
 - a. Having someone read them aloud
 - b. Listening to them being read on tape, CD, MP3, etc.
 - c. Having a computer read them
 - d. Reading them from hard-copy (paper) braille, in Nemeth Code
 - e. Reading them from hard-copy (paper) braille, but not using Nemeth Code
 - f. Reading them in braille using a refreshable braille display on a computer or note taker
 - g. Reading them in large print on paper

- h. Reading them using screen enlargement on the computer
 - i. Reading them using a CCTV or similar device
 - j. Something else (describe)
9. If the student's best method is not the same as the student's usual method, please explain why that is.

Enter your answer here:

10. Which best describes how convenient it is for you or the student to obtain math materials in formats that work with the student's best method for reading them? For example, if the best method is braille or large print, how convenient is it to obtain those materials? If the best method involves screen enlargement on the computer, how convenient is it for the student to get access to a computer with that software? If the best method is having a computer read them (in synthetic or prerecorded speech), how convenient is it to obtain the materials in a format a computer can read, and get access to a computer with a screen reader? If the best method involves having someone read it aloud, how convenient is it to arrange for the student and reader to meet when the student needs to have material read aloud?
- a. Very convenient
 - b. Somewhat convenient
 - c. Somewhat inconvenient
 - d. Very inconvenient

If you answered somewhat inconvenient or very inconvenient, describe the ways in which it is inconvenient or the types of materials that are inconvenient to obtain in the student's best method.

Enter your answer here:

11. In addition to text, most math materials contain mathematical expressions. It is important that students understand what each of these mathematical expressions is before they begin to work with it. Which best describes how well mathematical expressions are presented in the method the student usually uses to read math materials?
- a. Very well. The student can always, or almost always tell what the math expression is.
 - b. Well. The student can usually tell what the math expression is.
 - c. Not well. The student often has trouble telling what the math expression is.
 - d. Awful. The student usually can't tell what the math expression is.
12. Which best describes how easy or difficult it was for the student to learn to work with the student's usual format (when the student first started working with that format)?
- a. Very easy
 - b. Somewhat easy
 - c. Somewhat difficult
 - d. Very difficult

If you answered somewhat difficult or very difficult, describe what made it difficult.

Enter your answer here:

We also want to understand what experience, if any, the student has had with all the methods listed.

13. Which best describes the student's experience with having someone read or speak math aloud? Select all that apply:
- a. The student hasn't used it
 - b. The student is learning to use it
 - c. The student has used it, but finds it confusing
 - d. The student has used it, and it is helpful
14. Which best describes the student's experience with listening to math being read on tape, CD, MP3, etc.? Select all that apply:
- a. The student hasn't used it
 - b. The student is learning to use it
 - c. The student has used it, but finds it confusing

- d. The student has used it, and it is helpful
15. Which best describes the student's experience with having a computer read math with text-to-speech? Select all that apply:
- a. The student hasn't used it
 - b. The student is learning to use it
 - c. The student has used it, but finds it confusing
 - d. The student has used it, and it is helpful
16. Which best describes the student's experience with reading math from hard-copy (paper) braille, using Nemeth Code? Select all that apply:
- a. The student hasn't used it
 - b. The student doesn't read the braille math code well enough to use it
 - c. The student is learning to use it
 - d. The student has used it, but finds it confusing
 - e. The student has used it, and it is helpful
17. Which best describes the student's experience with reading math from hard-copy (paper) braille, but not using Nemeth Code? Select all that apply:
- a. The student hasn't used it
 - b. The student is learning to use it
 - c. The student has used it, but finds it confusing
 - d. The student has used it, and it is helpful
18. Which best describes the student's experience with reading math braille using a refreshable braille display on a computer or note taker? Select all that apply:
- a. The student hasn't used it
 - b. The student doesn't read the braille math code well enough to use it
 - c. The student is learning to use it
 - d. The student has used it, but finds it confusing
 - e. The student has used it, and it is helpful
19. Which best describes the student's experience with reading math in large print on paper? Select all that apply:
- a. The student hasn't used it
 - b. The student doesn't see well enough to use it
 - c. The student is learning to use it
 - d. The student has used it, but finds it confusing
 - e. The student has used it, and it is helpful
20. Which best describes the student's experience with reading math using screen enlargement on the computer? Select all that apply:
- a. The student hasn't used it
 - b. The student doesn't see well enough to use it
 - c. The student is learning to use it
 - d. The student has used it, but finds it confusing
 - e. The student has used it, and it is helpful
21. Which best describes the student's experience with reading math using screen enlargement on a CCTV or similar device? Select all that apply:
- a. Student hasn't used it
 - b. Student doesn't see well enough to use it
 - c. Student is learning to use it

- d. Student has used it, but it is confusing
 - e. Student has used it, and it is helpful
22. Which best describes how the student uses or does not use vision for math?
- a. The student usually or always uses vision by itself if the math is displayed in a way the student can use (with enlargement, the right font, the right color paper or screen display, etc.).
 - b. The student usually or always uses some combination of vision and other methods (braille, recordings, other assistive technology) to work with math.
 - c. The student usually or always uses nonvisual methods (braille, recordings, other assistive technology) to work with math.
23. Which best describes how the student uses computer screen readers (such as JAWS, NVDA, Window-Eyes, VoiceOver, etc.) for school work or homework, other than math or science.
- a. The student has never used a screen reader.
 - b. The student uses screen readers sometimes, but only when s/he can't get material in a format s/he prefers (such as braille or large print).
 - c. The student uses screen readers with about the same frequency and preference as other formats, such as braille or large print.
 - d. The student uses screen readers and prefers them to material in other formats, such as braille or large print.
24. Which of these screen readers has the student used? Mark all that apply.
- a. JAWS
 - b. NVDA
 - c. Window-Eyes
 - d. VoiceOver
 - e. ZoomText with Speech
 - f. Other (describe)
 - g. Never used a screen reader
25. If your students with visual impairments could read math using a screen reader, what things would you want the screen reader to be able to do? Think about how it would speak the math and allow students to move around inside (that is, navigate) the math.

Enter your answer here:

26. We have conducted some earlier studies for this project. Please read the descriptions and mark which ones, if any, the student participated in, or you think the student might have participated in:

Study A.

In the spring of 2012, we conducted a study where students listened to prerecorded computer speech. Students might have used an MP3 player to listen to it, or may have used a media player on the computer. In that study, students were asked to answer math questions where the computer spoke the math in three different ways, and then let us know which ways of speaking the math were easiest to understand.

Study B.

In the spring of 2013, we conducted a study where students listened to the Window-Eyes screen reader reading math in Microsoft Word files. We asked questions like, "How helpful for telling what was under the square root were the wording and the way it was paced?"

Study C

At the end of 2014 or the beginning of 2015, we conducted a study where students went through a tutorial on navigating math expressions using the NVDA screen reader, and then answered feedback questions about the tutorial and the methods taught for using arrow keys, zooming in and out, and using place markers.

To your knowledge, which of these studies, if any, do you think the student participated in or may have participated in? Mark all that apply:

Study A

Study B

Study C

None of them

Finally, we would like your assessment of the student's math proficiency.

27. Please rate the student's proficiency with fractions in algebra problems
- Developing
 - Proficient
 - Advanced
28. Please rate the student's proficiency at working with square roots in algebra problems
- Developing
 - Proficient
 - Advanced
29. Please rate the student's proficiency at working with math statements using parentheses in algebra problems
- Developing
 - Proficient
 - Advanced

Pilot Authoring Study Background Survey

Please type the letters corresponding to your responses in the spaces provided.

1. What is your typical role in the math classroom (indicate all that apply)?

- Math teacher
- Teaching aide / Paraprofessional
- Teacher of the Visually Impaired
- Administrator
- Teaching consultant
- Other _____

Response: _____

For the remainder of the questions, if you are not a teacher, interpret "teach", "taught," etc. as it best applies to your typical role.

2. Which math classes do you generally teach (indicate all that apply)?

- Pre-algebra
- Algebra 1
- Algebra 2
- Other Algebra
- Geometry
- Pre-calculus
- Calculus
- Other _____

Response: _____

3. How long have you been teaching math?

- Less than 5 years
- 5–10 years
- 10–20 years
- More than 20 years

Response: _____

4. How many blind (no usable vision) students have you taught over the past 5 years?

- A. None
- B. None so far, but expect to do so in the near future
- C. None in the past 5 years, but some students more than 5 years ago
- D. 1–2
- E. 3–5
- F. 5–10
- G. 10–20
- H. More than 20

Response: _____

5. How many students with visual impairment (but with some usable vision) have you taught over the past 5 years?

- A. None
- B. None so far, but expect to do so in the near future.
- C. None in the past 5 years, but some students more than 5 years ago
- D. 1–2
- E. 3–5
- F. 5–10
- G. 10–20
- H. More than 20

Response: _____

6. Other than teaching or other academic contexts, do you have any experience working with individuals with visual impairments? If so, briefly describe below:

7. Which of the following math and/or assistive technology tools do you feel comfortable working with and/or teaching? (indicate all that apply)

- A. MathType
- B. MathPlayer
- C. Scientific Notebook
- D. Other math tool: _____
- E. JAWS
- F. Window-Eyes
- G. NVDA
- H. VoiceOver
- I. Other screen reader: _____
- J. Zoomtext
- K. MAGic
- L. Other screen magnifier: _____

Response: _____

8. In what setting(s) do you teach (indicate all that apply)?

- A. School for the blind or visually impaired
- B. Itinerant
- C. Inclusive classroom

Response: _____

9. Did you participate in the Authoring Feedback Study for this Project, which was conducted late in 2014? (Answer yes or no).

Appendix D
Authoring Assessment Instrument
Authoring Study Assessment Instrument

Estimated time: 1 hour.

Please save this instrument under the name Pilot AuthoringAssessment-xx.doc, replacing the “xx” with your participant ID code. For example if your id code is “06” the file should be named Pilot AuthoringAssessment-06.doc. Also, please write your participant ID here:

ID: _____

Directions

Enter each Math expression so that it speaks as indicated. It is highly desirable that an expression speak as indicated via rules and preferences, without adding exact speech, because exact speech can interfere with interactive navigation of the expression. However, this is not always possible. If you encounter an expression that you cannot get to speak as indicated using only the rules and preferences, it is good practice to use rules and preferences to get the speech as close as possible to the speech indicated, and then use exact speech to adjust the speech for portions of the expression that do not speak as indicated.

Expression 1: $1 + \sqrt{2x + y} - z$

Desired Speech:

1 plus the square root of 2x plus y, minus z

Enter Expression 1 here:

Expression 2: $2(3x + 1)^2 + \frac{x + 4}{3} - 5$

Desired Speech:

2 times, open paren, 3 x plus 1, close paren, squared, plus, the fraction x plus 4, over 3, minus 5

Enter Expression 2 here:

Expression 3: 3.000001

Desired Speech:

3 point zero zero zero [300 ms pause] zero zero one

Enter Expression 3 here:

Expression 4: $12x^6 + 18x^2 + 35x^7 + 5x^{15} + 45 + 16x^{12}$

Desired Speech:

12 x to the sixth, plus 18 x to the second, plus 35 x to the seventh, plus 5 x to the fifteenth, plus 45, plus 16 x to the twelfth

Enter Expression 4 here:

Expression 5: $3x + 2 + 6x + 8 + 4x$.

Desired Speech: 3 x plus 2 plus 6 x plus 8 plus 4 x

Enter Expression 5 here:

Expression 6: $2(3 + 1) + 4(3 + 2)$

Desired Speech:

2 times, open paren, 3 plus 1, close paren, plus, 4 times, open paren, 3 plus 2, close paren

Enter Expression 6 here:

Expression 7: $3(2 + 3)^2(4 - 2)^3$

Desired Speech:

3 times, open paren, 2 plus 3, close paren, squared, times, open paren, 4 minus 2, close paren, cubed

Enter Expression 7 here:

Expression 8: $2((3 + 7) - 4(6 - 4)) - 1$

Desired Speech:

2 times, open paren, open second paren, 3 plus 7, close second paren, minus, open second paren, 6 minus 4, close second paren, close paren, minus 1

Enter Expression 8 here:

Expression 9: $\frac{(x + 1)(2x - 3)}{(2x + 1)(x + 1)(2x + 3)}$

Desired Speech:

The fraction with numerator, open paren, x plus 1, close paren, times, open paren, 2 x minus 3, close paren, and denominator, open paren, 2 x plus 1, close paren, times, open paren, x plus 1, close paren, times, open paren, 2x plus 3, close paren

Enter Expression 9 here:

Expression 10: $\frac{3^{12}}{3^4}$

Desired Speech:

the fraction with numerator 3 to the twelfth power and denominator 3 to the fourth power

Enter Expression 10 here:

Expression 11: $\frac{x^{10} \cdot y^{12}}{x^7 \cdot y^{15}}$

Desired Speech:

The fraction with numerator x to the tenth power, times, y to the twelfth power, and denominator x to the seventh power, times, y to the fifteenth power

Enter Expression 11 here:

Appendix E

For a version of this report that is fully accessible using the tools described, download the Microsoft Word document located at <https://www.ets.org/Media/Research/RR-17-13.docx>. Accessible reading also requires:

MathPlayer: <http://www.dessci.com/en/products/mathplayer/download.htm>.

MathType: <http://www.dessci.com/en/products/mathtype/default.htm>.

MathPlayer is free; MathType is a paid product, but is available for free trial.

If screen reader integration is desired, download the free NVDA screen reader: <http://www.nvaccess.org/download/>.

Additional tools, tutorials, and related information can be found at <http://www.clearspeak.org>.

Suggested citation:

Frankel, L., Brownstein, B., & Soiffer, N. (2017). *Expanding audio access to mathematics expressions by students with visual impairments via MathML* (Research Report No. RR-17-13). Princeton, NJ: Educational Testing Service. <https://doi.org/10.1002/ets2.12132>

Action Editor: Heather Buzick

Reviewers: Ruth Loew and Elizabeth Stone

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