Using Description to Convey Mathematics Content in Visual Images to Students Who Are Visually Impaired

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Structured abstract: *Introduction:* Because of the preponderance of visual images, many mathematics texts are wholly or largely inaccessible to students who are blind. This study investigated how much description is sufficient to communicate math content in different types of images. *Methods:* Representative math textbooks from grades five, eight, and 11, aligned to the Common Core, were selected. Mutually exclusive and exhaustive image categories were identified. Clear examples of each image category were chosen, and digital files were created containing the examples and surrounding textual material. Files replicated the printed page as closely as possible, and all elements (words, math expressions, and descriptions of images) were readable by JAWS. Forty-four students who are visually impaired (that is, those who are blind or had low vision) listened to the math pages and answered questions related to the content contained in the images. *Results:* Students answered content-related questions better with more description, but across four description conditions with varying amounts of description the highest correct rate was low (29%). In looking at individual image categories, students had the most correct answers for number lines (41.0%). Rates of 20% to 33% correct were demonstrated for image categories of shapes, tables, line graphs, bar graphs, and ray diagrams. Correct rates for equations, pie charts, and maps were inconsistent or lower than 15%. Students were positive about math and did not indicate many problems with math texts. *Discussion:* Descriptions of visual images can communicate important math information, but there are images for which no level of description is sufficient. Many students in the study were not aware of how much visual math content to which they were not provided access. *Implications for practitioners:* Math texts need to be more accessible for students who are visually impaired. Although describing visual images can improve access to content, that may not be sufficient. Materials should be provided in several formats simultaneously so students can approach material in the mode that fits their needs in a variety of contexts.

Many of the estimated 601,100 students aged 5 to 20 years with visual disabilities in the United States (Erickson, Lee, & von Schrader, 2015) have difficulty accessing content in STEM (science, technology, engineering, math) texts (Beck-Winchatz & Riccobono, 2007). Many efforts to make mathematics accessible to visually impaired students tend to focus on technology that reads and speaks equations (Bouck, Flanagan, Joshi, Sheikh, & Schleppenbach, 2011) or is limited to descriptions of images such as line graphs (Gardner & Bulatov, 2008; Summers, Langston, Allison, & Cowley, 2012). More recent technological innovations have attempted to make certain types of charts and graphs more accessible to visually impaired students (Gardner, 2016). One area of development is the use of "sonification," in which changes in tone and volume represent features of the image, particularly for line and bar charts and for equation graphs (Davison, 2012, 2013; Walker & Mauney, 2010).

However, many math texts are increasingly full of visual images that contain critical mathematical content that is not accessible through any current technology (Cryer, 2013; Gardner, Stewart, Francioni, & Smith, 2002; Gould, Ferrell, & O'Connell, 2009). This content is accessible to students who are visually impaired only through some sort of description. Although there is evidence that good descriptions of STEM (science, technology, engineering, and mathematics) content enhance students' grasp of the material (Ely, Wall Emerson, Maggiore, O'Connell, & Hudson, 2006), and that audio description of science has a positive effect on visually impaired adults (Kirchner & Schmeidler, 2001), descriptions available to a student may not always be accurate or helpful (Rowlett & Rowlett, 2009). Readers in a student's classroom and the creators of written descriptions spoken by software programs might not be familiar with the content the image is trying to convey or the relationship the content has with the student's immediate task. Gould et al. (2009) found, in a survey of visually impaired scientists and professionals, that brief descriptions focusing on data instead of visual elements were preferred.

The purpose of the current exploratory study was to describe different types of images used in mathematics textbooks and to explore what happens when various levels of description are used in place of images. We sought to identify which level of description is most useful for specific types of images in math problems where use of the image is necessary for completing the problem. These results seek to inform creators of accessible materials about the level of description that may be necessary for students to complete different types of problems. This paper reports the results of students' ability to use descriptions of different levels of specificity, while a companion article (Wall Emerson & Anderson, 2018) reports results of the categorization of images within the math texts used.

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Table 1
Mathematic texts used in the study.

Grade	Title	Publisher
5	*Math Connects 5*	Macmillan
5	*Investigations*	Pearson
8	*Course 3 Math Common Core*	Prentice Hall
8	*Pre-Algebra*	Glencoe
11	*Geometry*	Prentice Hall
11	*Algebra 1*	Prentice Hall
11	*Algebra 2*	Prentice Hall
11	*Geometry*	Glencoe
11	*Algebra 1*	Glencoe
11	*Algebra 2*	Glencoe

Methods

MATERIAL PREPARATION

Math texts from grades five, eight, and 11, commonly used in general education that used the Common Core as a basic organizational feature, were chosen for use in the study (see Table 1). Both primary researchers, along with two graduate students, went through an iterative process of open coding followed by a process of axial coding to create a set of exhaustive and mutually exclusive image categories. This process is explained in more detail in the companion article (Wall Emerson & Anderson, 2018). The final list of image categories and their definitions are shown in Table 2.

The two principal investigators and two graduate students coded sample pages until all coders were reliable with one another above the 90% level. This coding demonstrated that images generally could not be described in isolation of context. Most images were directly connected to larger portions of content about half a page long that introduced concepts, guided readers through an example, or provided an explanation of concepts or skills.

Each textbook was reviewed to find up to five examples of each image category used in such a way that the image and the surrounding textual material constituted a conceptually "stand-alone" piece of text with as few other images as possible. Some combinations, especially those involving manipulatives or descriptions of a real-world task, were infrequent or not available at all. The resulting large set of examples of image categories was too large for reasonable testing under traditional experimental procedures. The decision was made to reduce the number of image categories used in the study to those that contained the highest proportion of mathematical content. The final 11 image categories used were question-specific images, equations, shapes, tables, scatterplots or line graphs, bar graphs, direction or illustration of a physical task, pie charts, number lines, ray diagrams, and maps (see Table 2).

Each image example and the surrounding textual material was typed and formatted in Microsoft Word to resemble, as closely as possible, the format on the printed page, preserving use of boldface, color changes, font changes, spacing, and alignment. MathType was used to create all mathematical expressions in the material. Four versions of each file were saved, each with a different level of description inserted for the target image within the file. The least amount of description was the "control" condition, in which there was no description except for the word "image" to represent the image. The next level of description was the "terse" condition, in which a brief indication of the general image was provided; an example might be "there is a line graph." The third level of description was "NCAM," which used the current standard protocol for

Table 2
Image categories with definitions.

Image category	Definition
Side image	An image meant to make content approachable but not content-related, such as background pictures, colored borders, or bolded titles.
Balloon or sidebar	Information set apart from the main text, question, or flow of information, generally in a box in the margin or in a bubble.
Screen shot	Actual image of a computer screen or graphing calculator screen.
Question-specific image*	An image that relates specifically to a question. This is a broad category and includes images that do not fall into other categories.
Picture in a picture	A situation where one category of image is totally subsumed within another image but where the two images cannot be separated.
Procedural aid	Information presented to assist a reader in performing a mental task.
Organizational chart	An image where the way the information is organized is key to what is being communicated. Often used to classify concepts.
Flow chart	Information where an essential feature is the sequential ordering of steps. Often uses a series of arrows between text boxes or the text.
Equation*	An equation with elements that may not be communicated by software designed to read math. This can include portions being different colors, or having check marks or x marks on parts of the equation.
Shapes (2D or 3D)*	An image whose essential information is shape related.
Table*	Information organized in a tabular format.
Scatterplot or line graph*	Information presented as a series of x and y coordinates on a graph or a line of points on a graph. Data points might be connected by lines or not, or the graph may contain a regression line.
Pattern or series	Information where the essence of the information is the building of a pattern from one piece of the image to the next.
Bar graph*	Information presented in bar form, vertical or horizontal.
Direction or illustration of a physical task*	Information that shows the reader how to do a real-world task.
Pie chart*	A circular presentation of data.
Number line*	A straight line with graduated numbering along it, used to illustrate the sequential nature of some information.
Ray diagram*	An image that portrays angles. The simplest version is two rays extending out from a vertex. A more complex example is a demonstration of complementary angles using two parallel lines by a transversal.
Model	An image where representations of items are used in place of the actual items, often for the purpose of generalizing an idea. An example is simplified images of cats and dogs used in a question about classification.
Calculator-related	Directions for using a calculator, often with images of calculator keys.
Map*	Information presented in the form of a map.

* Indicates a category used in data collection with students.

image descriptions as developed by the National Center for Accessible Media (NCAM) at WGBH in Boston. It is the standard guidance for image description used by Benetech and DIAGRAM in their Poet image description tool (see NCAM, n.d.; Rothberg & Gould, 2010). The fourth level of description was "extended," in which any element of the image that the description creator deemed potentially useful to a student was included in the description. Descriptions were written by a certified teacher of children with visual impairments who had also been trained by Benetech as a description writer and who worked for Benetech in training other description writers. This professional also had a background in assistive technology and science and was familiar with mathematical concepts and their description.

Each Microsoft Word document containing formatted text, MathType expressions, and inserted descriptions was rendered into an html document that could be output by speech software. In this process, the MathType expressions were rendered into MathML. The speech software chosen for this study was JAWS; it was chosen because it is the speech engine most commonly used by individuals with visual impairments (Center for Persons with Disabilities, 2015). Speech output settings for JAWS were established that optimized the pronunciation of MathML and formatted text, and that spoke at an understandable rate for listeners who were new to the JAWS voice. The JAWS voice was set to vary tone when reading different text formats such as text in boldface.

PARTICIPANTS

Participants in this study were 44 students with blindness or severe low vision from one of two schools for students with visual impairments ($n = 39$) or who attended public school ($n = 5$). Students were enrolled in the study according to the grade level of the mathematics they were studying, with the targets being grades five, eight, and 11, as determined by their mathematics teacher. The educators who were responsible for teaching mathematics to students nominated students who were operating at a grade five, eight, or 11 level for inclusion in the study. Students were included in the study if they did not have any other disabilities that would affect their performance in the study. There were three students operating at the grade-five level, 15 at the grade-eight level, and 26 at the grade-11 level. Ages of the students ranged from 10 to 21 years ($M = 16.02$, $SD = 2.14$). There were 32 males and 12 females. There was a range of ethnicities, with 17 students being Hispanic, 16 Caucasian, 7 African American, 1 Asian American, 2 who identified themselves as representing multiple groups, and 1 who selected "other." The students were often unsure of their visual acuity or visual designation, so whether they accessed math texts in braille or in some form of print was used as a proxy for visual status. Using this proxy, there were 25 students who were blind (that is, braille users) and 19 students with low vision. At the grade-five level, 1 student was blind and 2 had low vision; at the grade-eight level, 9 students were blind and 8 had low vision; and at the grade-11 level, 15 students were blind and 9 had low vision. In terms of self-reporting the cause of their visual impairment, 11 students reported "congenital" without further information; 5 reported retinal detachment; 4 reported nerve damage; 3 reported Leber's congenital amaurosis; 3 reported retinitis pigmentosa; 2 each reported macular degeneration, optic nerve hypoplasia, and optic nerve atrophy; and 1 each reported aniridia, Best disease, brain tumor, cataracts, cone dystrophy, meningitis, microphthalmia, reaction to sand, result of surgeries, severe combined immune deficiency syndrome, Stargardt's syndrome, and "undiagnosed."

DATA-COLLECTION METHOD

Schools for blind students and large metropolitan centers were canvassed to opt in to involvement in the project and to allow recruitment of visually impaired students operating at grades five, eight, or 11 levels in mathematics. Students were recruited from only three sites: Texas School for the Blind and Visually Impaired, Tennessee School for the Blind, and a public school in the Chicago area. Students were recruited in accordance with procedures approved by the Institutional Review Board of Western Michigan University. Each student was asked to listen to a selected portion of a math text, never more than half a page in length and never more than 150 seconds long (average length = 50.5 seconds, *SD* = 31.3), and then was asked to answer content-related questions that drew information from the target image described in the material to which the student listened. Due to time limitations, students would not be able to listen to several examples of every image category described at each level of description, so each student listened to a random selection of image category and description levels. In order to reduce fatigue in students, each listened to a maximum of 20 files. The range of trials a given student listened to was from nine to 20, depending on how long each trial took to complete. The experimenter controlled the starting and stopping of the speech software, so the student only had to listen and then answer questions about the material. Students were allowed to ask for anything to be read through again until they felt they were ready to answer questions on the material. No question required mathematical calculations, but were related only to content contained in the described image.

Students were also asked a series of open-ended questions about the format of their math textbooks, any tools or aids they used to access math content, their attitudes toward mathematics, any issues or problems with math texts or assessments, and their impressions of the descriptions they listened to in the study.

Results

ATTITUDES TOWARD AND ACCESS TO MATH

In addition to wanting to know about how to describe mathematical images for visually impaired students, we were interested in gauging their level of interest in and engagement with mathematics. Little is known about the attitudes of visually impaired students toward math and how they typically access mathematical material in the classroom. For open-ended questions, student responses were collated and grouped according to themes. Answers to most questions tended to fall into very definite themes. For example, when asked how they felt about math, 25 of the 44 students were positive, 11 were negative, and eight were neutral. When asked whether they were good at math, 32 of the 44 students said yes, five said no, six were neutral in their response, and one gave no response. These patterns of responses were the same across grade levels. No student expressed levels of negativity about math that suggested they would not be able to listen to samples from math texts and answer simple questions.

When asked to indicate their current reading format, 23 indicated braille alone and two indicated braille with support from audio; thus, these students represented what we considered to be the group of students who were blind. Seven students used large print, six students read print through a CCTV, five used print,

Table 3
Methods used to access mathematics in the classroom.

Method	Frequency
Braille, braille texts	20
CCTV	12
Auditory, reader, teacher	5
BrailleNote, Apex	5
Calculator	4
Large print	4
Book	3
Computer, software	3
Braille writer	2
Dry erase boards	2
Tactile objects	2
Visio book	2
iPhone	1

and one used only audio; these students made up the group of students who were in the low vision category. There were braille and non-braille users in each grade level.

Most students did not know the title or publisher of their current mathematics text (59.1%). Apart from their general reading format, they were asked specifically how they accessed mathematics in the classroom. These data are shown in Table 3.

Many students did not indicate that they had any problems with math texts (40.9%). The problems they did note were about braille errors ($n = 8$); confusing graphs or tactile graphics ($n = 7$); confusing code ($n = 6$) in the Nemeth Braille Code for Mathematics and Science Notation (hereafter, Nemeth code) format; omitted pages, problems, or pictures ($n = 3$); poor large print contrast or size ($n = 3$); pages out of order ($n = 2$); not getting a braille text at all ($n = 2$); and confusing computer braille ($n = 1$). They were also asked about possible problems with math assessments, but the majority indicated they had none (77.3%). Those who did describe problems, rather than talking about obstacles in the tests themselves, referred to test-taking issues such as being nervous, not having enough time, or that the test was harder than homework.

DESCRIPTION CONDITION RESULTS

As was noted earlier, there were four levels of description that students listened to, and these levels of description were applied to examples of 11 different mathematics image categories. Each student listened to nine to 20 randomly selected combinations of image category and description level. This random assignment of categories and description conditions resulted in an even distribution of the four description conditions. There were 148 trials with the “control” condition, 147 with the “terse” condition, 151 with the “NCAM” condition, and 155 with the “extended” condition. The four description conditions were also evenly distributed across grades, $\chi^2(6) = 2.91$, $p = 0.82$; and across image category, $\chi^2(30) = 37.95$, $p = 0.15$. The 11 math image categories used were not equally represented in our sample, primarily because one category, “direction or illustration,” was less represented within the texts. The frequencies of the different image categories are shown in Table 4.

The frequency with which students correctly answered content-related questions was analyzed with the “direction or illustration” image category removed because questions about that category were not related to mathematics. There was a significant difference in correct answers across description categories, $\chi^2(3) = 17.66$, $p = 0.001$. Students averaged 15.1% correct for the control condition,

Table 4
Frequencies of image categories.

Image category	Frequency
Question-specific image	83
Equation	35
Shape	53
Table	50
Line graph	68
Bar graph	65
Direction or illustration	12
Pie chart	43
Number line	40
Ray diagram	73
Map	79

13.6% for the terse condition, 28.8% for the NCAM condition, and 28.6% for the extended condition.

Looking at the percentage of correct answers by image category, there was a significant difference in correct answers across description categories, $\chi^2(9) = 28.43$, $p = 0.001$. The percentage of correct answers, by image category, is shown in Table 5. The results show that students most often answered questions about number lines correctly, with correct rates of 41.0%. A second tier of correct rates, ranging from 20% to 33%, includes shapes, tables, line graphs, bar graphs, and ray diagrams. Correct rates for question-specific images, equations, pie charts, and maps were inconsistent or lower than 15%. Note that a limitation to these correct rates is that questions constructed for each image could not be equated with one another regarding difficulty. However, in general, content-related questions simply asked for a piece of information about the content and did not require the use of the information to do computations.

Table 5
Percentage of correct answers by image category.

Image category	Percentage correct
Question-specific image	15.1
Equation	5.7
Shape	22.6
Table	32.0
Line graph	32.8
Bar graph	22.2
Pie chart	14.0
Number line	41.0
Ray diagram	19.2
Map	14.1

Direction or illustration category was removed due to low occurrence.

STUDENT PERCEPTIONS OF DESCRIPTIONS

After students had listened to and responded to all the math conditions allotted to them, they were asked a series of questions about their perceptions of the presentations they listened to. Note that because of the random assignment of conditions each student was exposed to, some may have listened to more or less of any one of the four levels of description, which might have skewed their perceptions of the presentations overall. As such, an overview of data from these answers is provided instead of detailed data. These results are closely affected by what exactly the students were listening to and what they were asked to do with the information they listened to. Too much and not enough information were both cited as bad aspects of the descriptions. These instances were directly tied to the kind and amount of information being relayed. Similarly, there were many comments about the voice used to speak the selections of math. We used the JAWS program with the same settings for all students. Students reacted to the JAWS voice depending on their preferences and amount of previous exposure to it. Finally, a number of comments were made about the limitation that only audio was provided for the math content and a braille version, a tactile graphic, or both were not also provided, which may have helped students to better understand what was being communicated.

When asked what needed more and what needed less description, students most frequently indicated that "pictures" (n = 16) and graphs (n = 16) needed more description; many also said that "nothing" (n = 13) needed less description. Students' answers were somewhat confounded due to the specific description condition they received for particular items in the presentations to which they had listened. When asked whether they would like absolutely everything on a page described, 24 said yes, 13 said no and only seven gave a qualified answer of "maybe" or "it depends." Although these results suggest that these students are desirous of more description, this desire might be an indication that there was a broader desire for greater access to content through any means and that description was just the mode being offered in this study. Along these lines, we asked students what would help their understanding of the material to which they had listened (see Table 6).

Many of these responses suggested instructional approaches that were not a part of this study but that can be used in the future to guide how such content is approached, including using a more guided approach, giving more time and control to the student to explore visually based material, and using a more human-sounding voice output program. These responses echo the largest response category and seem to indicate that foreknowledge of some sort of overall structure or formatting of the content helps with understanding. Along with this thread, responses about also having braille or tactile versions of what is being listened to would help with a student's ability to grasp an overall structure and place the visual material into a context to aid with understanding.

Table 6
Student perceptions of what would help understanding of mathematics content.

Response	Frequency
Explaining formatting (on page and in graphs)	9
Not switching voices, clearer voice	7
Human voice instead of computer	6
Nothing, it is fine	5
More information	5
Braille version	4
Less information	3
Better information	3
Tactile graphics	3
Chance to review material	2
Control over the program	2
Less error	1
More lead-in to upcoming graphs	1
Slower speech	1
More examples	1
Simplify things	1

Discussion

There were four levels of description used in this study. Students had similar rates of correct answers between the control and terse description conditions (which had the least amount of description), and those correct rates were approximately half that of the NCAM and extended description conditions. However, even for the NCAM and extended conditions, the rate of correct answers was always less than 29%. Students most often answered questions about number lines correctly about 41.0% of the time. A second tier of correct rates, ranging from 20% to 33%, includes shapes, tables, line graphs, bar graphs, and ray diagrams. Correct rates for question-specific images, equations, pie charts, and maps were inconsistent or lower than 15%.

Even though the rate of correct answers was relatively low, even for the highest level of description, of the 44 students in this study 25 felt positive about math and 32 indicated that they were good at math. These numbers were higher than what was expected by the experimenters, especially given the prevalence of "math anxiety." The students in the study were identified as 25 primary braille users and 19 students who used a variety of large print, CCTV, print, or audio. Although this study was undertaken because of an identified problem with making math texts accessible for visually impaired students, many students in the study did not note any problems with math texts (40.9%). Problems noted were generally not about the math but referred to braille errors; confusing graphs or tactile; confusing Nemeth code; omitted pages, problems, or pictures; poor large print contrast or size; pages out of order; not getting a braille text at all; and confusing computer braille.

How well students could answer content-related questions was closely affected by exactly what they listened to and what they were asked to do with the information they listened to. Students cited both too much and not enough information as bad aspects of the descriptions, depending on the kind and amount of information being relayed. Similarly, they reacted to the JAWS voice depending on their preferences and amount of previous exposure to JAWS. Students also commented about the limitation of only audio being provided without a braille version, a tactile graphic, or both, which may have helped them to better understand what was being communicated. Overall, there was a strong desire for more description of pictures and graphs. Half of the students expressed a desire for a description of every visual element on the page. Overall, these results suggest that these students are desirous of more description. However, as was noted earlier, this desire might be an indication that there was a broader desire for greater access to content through any means and that description was just the mode being offered in this study. In general, describing content contained in visual images improves access to texts, but description alone is not sufficient. Materials should be provided in a range of formats simultaneously so that students can approach it in the mode with which they are most comfortable and that fits the needs of the situation.

LIMITATIONS

This study had several limitations that can affect the generalization of the findings. For one, students involved in the study were chosen from only three educational locations. Although two of the sites were schools for students with visual impairments and one was a public school setting, the majority of the participants came from the two special schools. The participants did represent a range of backgrounds, however, the lack of diversity in site locations might limit the generalization of the findings. Although the intent of the study was to collect data on students in grades five, eight, and 11, there were very few grade five students who were recruited into the study. The small number of fifth graders allowed a robust study of later mathematics (for students in grades eight and 11), but as a result little is still known about the attitudes and issues with students in lower grades.

An important limitation in the study design was the fact that, due to the large number of image categories and description conditions, no student could be exposed to every combination of image type and description condition, and certainly not with repetitive trials in each combination. A Latin squares design was not as effective as a random list of conditions, due to the small number of trials a given student could be exposed to in comparison to the total number of condition combinations possible. Since this study represented an exploratory examination of the topic, this limitation was deemed acceptable in order to begin addressing the issue. Similarly, the questions asked of students were simple, straightforward questions about math content contained in images. However, due to the many ways information was presented in images, it was not possible to equate questions across image types, and so it is possible that some questions were more difficult than others.

Finally, students were not able to control their experience with listening to the math content, but rather listened passively. Although they could repeat the materials, being in active control of the experience might have increased their acquisition of the content. Not having the material in tactile form such as braille might also have been limiting to some students if they were not strong auditory learners.

References

Beck-Winchatz, B., & Riccobono, M. (2007). Advancing participation of blind students in science, technology, engineering, and math. *Advances in Space Research, 42*(11), 1855–1858.

Bouck, E. C., Flanagan, S., Joshi, G. S., Sheikh, W., & Schleppenbach, D. (2011). Speaking Math: A voice input, speech output calculator for students with visual impairments. *Journal of Special Education Technology, 26*(4), 1–14.

Center for Persons with Disabilities. (2015). *WebAIM: Web accessibility in mind. Screen reader user survey #6 results.* Retrieved from http://webaim.org/projects/screenreadersurvey6/

Cryer, H. (2013). *Teaching STEM subjects to blind and partially sighted students: Literature review and resources* (Literature review #6). Birmingham, UK: RNIB Centre for Accessible Information. Retrieved from https://www.rnib.org.uk/sites/default/files/2013_05_Teaching_STEM.docx

Davison, B. K. (2012). *Understanding how visually impaired students demonstrate graph literacy with accessible auditory graphs* (doctoral proposal). Georgia Institute of Technology, Atlanta, GA. Retrieved from http://sonify.psych.gatech.edu/~ben/files/HCC/davison.thesis.v31.pdf

Davison, B. K. (2013). *Universal graph literacy: Understanding how blind and low vision students can satisfy the Common Core Standards with accessible auditory graphs* (doctoral dissertation). Retrieved from https://www.smartech.gatech.edu/handle/1853/47621

Ely, R., Wall Emerson, R., Maggiore, T., O'Connell, T., & Hudson, L. (2006). Increased content knowledge of students with visual impairments as a result of extended descriptions. *Journal of Special Education Technology, 21*(3), 31–43.

Erickson, W., Lee, C., & von Schrader, S. (2015). *Disability statistics from the 2013 American Community Survey (ACS).* Ithaca, NY: Cornell University Employment and Disability Institute (EDI). Retrieved from www.disabilitystatistics.org

Gardner, J. (2016). *Emerging computer technologies for accessible math.* Retrieved from https://viewplus.com/emerging-computer-technologies-for-accessible-math

Gardner, J. A., & Bulatov, V. (2008). *Making scientific graphics accessible with ViewPlus IVEO.* Proceedings of The 23rd Annual International Technology & Persons with Disabilities Conference. Los Angeles, CA: CSUN.

Gardner, J. A., Stewart, R., Francioni, J., & Smith, A. (2002). *Tiger, AGC and Wintriangle, removing the barrier to STEM education.* CSUN International Conference on Technology and Persons with Disabilities, Los Angeles, CA. Retrieved from http://www.csun.edu/~hfdss006/conf/2002/proceedings/299.htm

Gould, B., Ferrell, K. A., & O'Connell, T. (2009). Accessible science: How to describe STEM images. *AER Journal: Research and Practice in Visual Impairment and Blindness, 2*(1), 52–54.

Kirchner, C., & Schmeidler, E. (2001). Adding audio description: Does it make a difference? *Journal of Visual Impairment & Blindness, 95*, 197–212.

National Center for Accessible Media (NCAM). *Home*. (n.d.). Retrieved from http://ncam.wgbh.org

Rothberg, M., & Gould, B. (2010). *Effective practices for description of science content within digital talking books*. Proceedings of the 25th Annual International Technology & Persons with Disabilities Conference. San Diego, CA: CSUN.

Rowlett, E. J., & Rowlett, P. J. (2009). Visual impairment in MSOR. *MSOR Connections, 9*(4), 43–46.

Summers, E., Langston, J., Allison, R., & Cowley, J. (2012). *Using SAS/GRAPH to create visualizations that also support tactile and auditory interaction.* SAS Global Forum. Cary, NC: SAS Institute.

Walker, B. N., & Mauney, L. M. (2010). Universal design of auditory graphs: A comparison of sonification mappings for visually impaired and sighted listeners. *ACM Transactions on Accessible Computing*, *2*(3), 12:1–12:16.

Wall Emerson, R., & Anderson, D. L. (2018). What mathematical images are in a typical mathematics textbook? Implications for students with visual impairments. *Journal of Visual Impairment & Blindness, 112*(1), 20–32.

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