Teachers of Students with Visual Impairments Share Experiences and Advice for Supporting Students in Understanding Graphics

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Structured abstract: *Introduction:* Knowing how to gather information from graphics and to use that information to solve mathematics problems is an important skill. Prior research indicates that many students with visual impairments face considerable challenges when attempting to locate information in math graphics. Little is known about how teachers of students with visual impairments support their students in acquiring graphics skills. *Methods:* Eleven teachers of visually impaired students participated in focus groups. Sessions were audio-recorded and transcribed. Themes were identified. *Results:* The teachers described the importance of individualizing instruction for the student, teaching a systematic approach, and ensuring that graphics are clear to them. *Discussion:* From an early age, visually impaired students need explicit instruction in how to access information in graphics. The use of prescribed low vision devices, manipulatives, and systematic instruction are integral to student success, as are the design and production of clear and accurate graphics. *Implications for practitioners:* Teachers of visually impaired students utilize a variety of strategies to support students in accessing information in graphics. A curriculum and guidelines to assist them in supporting a wide range of learners would be valuable to the field of vision loss.

In our visual world, information is often presented in graphical format through diagrams, maps, and visual representation of data. Understanding mathematical relationships that are expressed in graphical form has been identified as a critical component of mathematics proficiency (Aldrich, Sheppard, & Hindle, 2003; Friel, Curcio, & Bright, 2001). Mathematics proficiency is a predictor of success in science, technology, engineering, and mathematics (STEM) careers. Unfortunately, visually impaired individuals (that is, those who

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are blind or have low vision) are dramatically under-represented in these fields (McDonnall, Geison, & Cavenaugh, 2009; National Science Foundation, Division of Science Resource Statistics, 2009). For visually impaired students to be competitively employed in STEM fields, they need to have strong graphics literacy skills. The authors define *strong graphics literacy skills* as the ability to efficiently, accurately locate and use information to complete tasks (for instance, to locate the heights of two bars on a bar graph to compare their values, tell the value of a category at a specific point on a line graph, or interpret a scatterplot to make a prediction).

Prior research indicates that visually impaired students often do not develop the skills to efficiently and accurately access graphical information. Beal and Rosenblum (2018) found that 43 visually impaired students in grades 4 to 10 required significantly more help from teachers of students with visual impairments when solving math word problems that involved graphics (such as maps, diagrams, and geometric figures) compared to similar math problems that did not include graphics Of the 16 braille readers in the study, only 5 were independent with the 16 problems that included graphics; the other 11 needed some level of assistance on at least one of the problems. Similar results were reported for the 27 print readers, and only 9 worked independently on all 16 graphics problems. The level of assistance the teachers of visually impaired students provided to the students in this study would not have been permitted on high-stakes tests (Allman, 2009).

Other research points to the challenges graphics present for visually impaired students. A survey of teachers of visually impaired students ($N = 306$) found that only about 20% felt their students could use math graphics independently (Zebehazy & Wilton, 2014b). Zebehazy and Wilton (2014a) found that visually impaired students self-reported that they were not able to keep up with sighted classmates on math tasks that involved graphics.

According to Zebehazy and Wilton (2014b), most teachers of visually impaired students indicated that the primary problem for their students was that they had not received explicit instruction in using graphics. Although the *Guidelines and Standards for Tactile Graphics* (Braille Authority of North America, 2010) provides support for preparing tactile graphics for braille readers, there are no guidelines for teachers of visually impaired students on how to introduce graphics to their students or how to teach them the systematic use of graphics as tools to gather information, nor are there guidelines on preparing graphics for visually impaired print readers. To gather preliminary information to guide our research team as we developed materials to support visually impaired students in building their graphic literacy skills, we conducted three focus groups with 11 teachers of visually impaired students.

Focus group participants typically have common characteristics and are assigned to discuss a specific topic under the direction of a moderator. The discussion allows the researchers to gain an in-depth understanding of members' experiences and beliefs about the topic (Krueger & Casey, 2015; Morgan, 1997). During a focus group, participants interact with each other and share similar or different opinions and experiences. By reacting to and building on other group members' responses, focus group members can generate ideas that would not be apparent in individual interviews (Morgan, 1997; Stewart, Shamdasani, & Rook, 2007).

The present study elicited examples from experienced teachers of visually impaired students about the challenges their students experience while using graphics and the strategies used to support these students. The focus group methodology has limitations, including the lack of independence of responses from participants (Stewart et al., 2007) and the location of appropriate participants because visual impairment is a very low-incidence disability. It could be difficult to identify and recruit enough teachers of visually impaired students for an in-person focus group in a particular location. Modern technology now makes it possible to assemble focus groups with participants who are geographically dispersed but who can work together in an online space (Langer, 2001).

Methods

The study was approved by the Institutional Review Board at the University of Florida. Participants provided consent as part of an online survey (see Rosenblum, Chen, Zebehazy, Wall Emerson, & Beal, in progress).

Questions

The first and third authors developed six open-ended questions that focused on visually impaired students and their access to information in graphics. Topics included: challenges low vision students experience with graphics, challenges blind students experience with graphics, defining what makes a student skilled at gathering information from graphics, considerations for developing an iPad application (app) and accompanying materials to support students in grades five to seven in building their graphics literacy skills, ways in which teachers of visually impaired students attempt to teach students to gather information from graphics, and how materials can be designed to give students opportunities to practice building their graphics literacy skills while keeping them motivated and successful.

Participants

A convenience sample was used. Five of the participants were known to the first author. The other six were nominated by three colleagues serving on the advisory board for a national project focused on building graphic literacy skills of visually impaired youths. The nominators were asked to share information about the study with teachers of visually impaired students who had sufficient vision to see images on the computer screen; who had extensive experience supporting students with visual impairments in math and science content; and who had been in the field for a minimum of three years.

Structure of the focus groups

Three focus groups were held; two had four participants and the third had three. The first author moderated the groups, and the third author took notes and occasionally asked clarifying questions. Based on participant availability, each teacher of visually impaired students was assigned to one of these three focus groups. The groups lasted 60 to 80 minutes, were audio-recorded, and were held using Zoom web-conferencing software. For each question, the order of participants answering was rotated so that the same participant did not always answer first, second, and the like. This method reduced the potential bias of the results caused by an opinionated member and did not pressure a participant to always answer first (Stewart et al., 2007).

Data coding

Using transcripts of the audio files, the researchers identified the trends and patterns of participants' perceptions (Krueger & Casey, 2015). Each audio file was transcribed by the first or second author. Both inductive and deductive analyses were used to analyze the transcripts. *Inductive analysis* refers to deriving concepts, themes, or a model through interpretation of raw data (Strauss & Corbin, 1998; Thomas, 2006), and *deductive analysis* refers to analyzing data to test whether the data are consistent with prior theories or hypotheses identified by the researchers (Thomas, 2006).

All authors read the three transcripts, and the first two authors used inductive analysis to identify and define 12 themes (see Table 1). The second author employed deductive analysis to code the transcripts using the identified themes. The first author reviewed the coded transcripts and noted disagreements. There were only two disagreements, and these were resolved between the two authors.

Results

In this section, themes that emerged from the transcripts are discussed with teachers of visually impaired students' quotes used throughout.

Participants

The 11 participants were female and White, and resided in the United States: 5 in Texas; 3 in Arizona; and 1 each in Illinois, Oklahoma, and South Carolina. Nine of them were itinerant teachers and 2 worked at schools for blind students where they taught math at the junior high school and high school levels. Their number of years of teaching ranged from 4 to 25, median 7 years, and mean 13 years.

Increasing access to graphics

These teachers shared the importance of ensuring that graphics were produced in an accessible manner for their students. For print readers, teachers noted that poor contrast, too much visual information, placement of labels, and the types of labels were factors that could impede a student's access to information in graphics. Almost all the teachers shared information about ways in which they changed the visual attributes of graphics to increase their students' access to print. The need to have lines and points that were visually distinctive, along with increasing contrast; changing or adding color; and using highlighting were described. Jane said, "For homework, [it] typically goes home in large print. [The student with low vision] will ask for certain things to be highlighted to make it easier to see." Kate commented, "For my low vision students, color seems to distract more than the contrast."

The participants recognized that visual access presents challenges for students with low vision at all grade levels. Gina explained a challenge a student faced with a circle graph: "[The student] had problems with contrast, because a circle graph has colors. [The student] had trouble with where the colors are. Labels are all over the place."

For braille readers, these teachers emphasized the importance of tactual clarity,

Table 1
Themes and their definitions.

Theme	Definition
Visual attributes of the graphic	Attributes of the graphic that impacted a student with low vision, including poor contrast, too much information, use of color, lack of color, type of labels, and placement of labels.
Content of the graphic	Time spent with the student on the math content, not just the graphic, including previewing, reviewing the graphic and content simultaneously, and making a template for the student to fill in with information obtained from the graphic.
Using low vision aids and manipulatives	Using prescribed optical aids, including handheld magnifiers and closed circuit televisions (CCTVs), including strategies for using the low vision aids such as having the student first use his or her eyes to look at the gestalt of the graphic and then using the CCTV to zoom in on key aspects of the graphic. Promoting increased understanding of the content presented in the graphic through 3-D models such as a cube, Geometros (APH), and stackables (APH).
Systematically going through material with the student	Having students find specific items on the graphic and teaching them how to use a systematic search pattern.
Enhancement of the graphic	Enhancing the graphic to promote student exploration through the use of rulers, sticky or foam dots, typoscopes, highlighters, a dot for a reference point, Wikki Stix, etc.
Simplifying the graphic	Simplifying the graphic for easier readability through fewer points in a scatterplot or dividing content into multiple graphics.
Using the language of the general education or math teacher	The importance of using the same language that the general education math teacher uses.
Teaching a systematic approach that the student can generalize across graphics	Starting students at a young age with graphics and teaching a systematic approach to exploration.
Connecting information in graphics to the "real world"	Helping the student make a connection between what is in the graphic and the real world, including helping them see angles in the environment, moving one's own body into the shape of an angle, and designing bar graphs based on one's own experiences.
Clarity of the prepared graphic	Preparing tactually clear graphics in order for the student who is a braille reader to interpret the graphic. Examples include clarity of lines, distinct textures, and avoiding lines that cross and feel too similar. For print readers, the teacher of visually impaired students describes the importance of clarity such as lines that are easily distinguishable.
Multiple modalities for learning	Use of visual, tactual, or auditory access to enhance learning, including the need for the student to hear the information while reading it and the use of games that allow for the generalization of skills.
Ideas for instructional materials	Structure or components to include in instructional materials to teach graphics literacy skills, including making it game-like, providing practice opportunities, teaching a systematic approach, and providing the student with feedback on his or her performance.

including clarity of lines, distinct textures, and avoiding lines that cross and feel too similar. They provided examples of ways in which they enhanced the students' exploration of the graphics, including the use of rulers; sticky or foam dots, including using a dot for a reference point; typoscopes; folding a piece of paper in half to use as a straight-edge; and using American Printing House for the Blind (APH) graph paper and Wikki Stix. They indicated the necessity of appropriate location for the problem or question and the graphic. They suggested putting the problem or question adjacent to the graphic so that students could read the information all at once and access information intermediately without having to lose track of where they were.

For both print and braille readers, the teachers talked about simplifying the graphics for easier readability; for example, by reducing the number of points in a scatterplot. They discussed times when dividing content into multiple graphics was beneficial; for example, converting a line graph with two lines into two separate graphics with one line each. Elle stated, "I start by eliminating some of the clutter and then bringing it back and showing them how they can do that themselves." Adaptations made to any one graphic were individualized based on student need.

Use of low vision devices and manipulatives

The teachers reported on the need for students to use prescribed optical devices, including handheld magnifiers and closed-circuit televisions (CCTVs). They described strategies provided to the student for using low vision that included having the student first use his or her eyes to look at the gestalt of the graphic and then to use the CCTV to zoom in on its key aspects. Elle explained that,

> I drill into my students with low vision . . . any number lines, any rulers, any measuring, I want their optical device right there . . . especially for the measuring, the number lines, anything with a ruler.

The teachers advocated using manipulatives to increase the understanding of the graphic. Specific manipulatives included: using 3-D models such as a cube; making a triangle out of paper fastened with a brad for students to actually rotate when working on problems focused on rotation; and APH products such as Geometros and stackables. Elle described how she used hands-on materials to help students grasp the concept of rotation.

> [With the student] sliding the actual shapes on the graph and then either outlining them or using Wikki Stix. Then [the students] being able to flip and rotate whatever they need to do and then being able to plot the points that way.

The teachers described the importance of students recognizing that the 2-D image is a representation of the 3-D image. Felicia pointed out the challenges in supporting students in developing an understanding of 2-D representations of 3-D objects:

> You never know what the 3-D graphic will look like. Every transcriber on every test will make them look a little bit differently. We do a lot of looking, [tactually] or looking with their eyes. We use a lot of stackables and the Geometros.

The teachers said that providing students with multiple methods (visual, tactual, or auditory) for accessing information was often valuable. Kate prepared graphics using a fuser (a machine that uses heat to raise any black marks on the page), and she found that the combination of the tactual and visual attributes was valuable to her students with low vision. Carol also noted the benefits of graphics produced using a fuser. "A lot of our kids are dual [media users]. They are technically tactile kids, but they are using the vision they have to access information as well." Teachers recognized that different students had different sensory strengths, and that part of their role was to identify the best way for them to gather information and to produce the graphic accordingly.

Developing students' content knowledge

Participants said that students often lacked foundational knowledge of the content needed to solve the math problems that involved graphics. They noted the importance of having the student spend time understanding the content before going to the graphic to locate information, and of supporting the student in identifying in the content what is being asked for from the graphic. Several teachers shared specific ways in which they guided students. One strategy was to have students say or write down what information they needed in order to solve the problem, to help them focus on what they were looking for in the graphic. Carol said:

> [In the problem] for a low vision student, we'll underline or highlight or circle or something. But for a blind student, I often have them write it down. So now they've taken this five lines of text information, and now they have their two things they are looking for or three things. . . . When they go back to the graphic, they have more of a focus.

Dawn made a template for students to use as they got information from the graphic. She noted that for some students the issue then became "[w]hat to do with that information once they have it to solve the problems also presents a little more of a challenge." Irene said that "[the students] don't know once they've got an idea of what's on the graph how to solve the problem that's related to it." The teachers emphasized the fact that it was necessary to make sure students have mastered the foundational content of the problem before using the graphic.

The teachers described the importance of helping the student make a connection between what is in the graphic and the real world. Dawn reported, "I just had a lot of students know what angles are . . . but not understand that [angles are] part of their daily life." She had her students move their own bodies into different angles. She also used objects to illustrate angles; for example, having the student use a book to form an angle. Elle used Sudoku puzzles to support students in exploring vertical and horizontal relationships. When talking about 3-D objects, Elle pointed out that, for math, students need ". . . the learning of the spatial relationships and the orientation of themselves and others or objects, compared to where they are."

Graphic exploration strategies

The teachers described ways in which they had students find specific information on the graphic. Several provided instruction to students in how to search for information; for example, top to bottom, left to right, or whole to part.

They talked about how, at an early age, they gave students opportunities to start building their graphics literacy skills. Jane reported:

> [With students] 3 to 6 years old [I use] a lot of tactile pictures to have them explore whole to part, top to bottom, and paying attention to fine details. As they get older, one of the fun activities we do is braille Sudoku. Students explore whole to part and part to whole on a 4 × 4 grid.

They reported that even as early as kindergarten, students are beginning to work with graphs such as simple bar graphs.

They discussed the importance of helping students develop their own systematic approach that they can generalize across the same type of graphic. Felicia said:

> I have a very specific step-by-step process for the student to explore a graph. Start at the top and read the title. Find the label for the x-axis. Find the y-axis on the left. Then we talk about the scale. "Let's look at the scale and find the numbers." Point out the dotted lines in between. Be sure the student really understands the scale from bottom to top and then goes across from left to right to find out what is going to be graphed.

In a broader sense, the teachers recommended that students develop consistent strategies to use when encountering any type of graphic, including finding the title, determining what kind of graphic it is, checking if there is a key, and deciding what to specifically look for. Helen stated:

> The kids develop a consistent strategy on how they are going to attack a graphic. They practice that strategy every time no matter if it is a scatterplot or graph. If they tick off the ideas in their head, they won't miss something like the key.

Teachers of visually impaired students shared how important it is for braille readers to use both hands when working with graphics. Several reported that they trained students to use one hand to read the question and the other to explore the graphic. Kate noted, "I find the students who are most successful have their hands on the graph"; and Carol said, ". . . being able to read the question again with the left hand while exploring the graphic with the right hand [helps] them along in the process [of developing efficient hand usage]." Elle stressed how she worked to shape the behavior of using two hands:

> I had my very first braille student years and years ago. She was really bad at tactile graphics. . . . She came to me as a one-handed braille reader, right hand. So she always would miss things on the left side and I'd always cue her to use that left side.

Teachers also suggested having students draw on the graphic or even to create graphics for themselves. By doing these things, they better understood the parts of the graph, map, or diagram they were viewing. Felicia said:

> When we were doing coordinate graphing like slope or rise over run, I like to let them draw on the graph and have them rise two, run three. If we are doing something like finding the intersection that can be confusing,

> especially if it is in the book, it can be difficult for them to find the lines and where they intersect. If I can let them draw, just trace the line, that can help them a lot.

Carol explained the benefits of having students create graphics:

> The act of getting to try to create it themselves is really a big part of it. I think making sure if they are reading the graphics, they are also creating the graphics. If they are reading a lot of maps, is there a situation in which the student can create a map so that they are getting that experience?

Other instructional strategies

Teachers stressed the importance of accommodating instructional approaches to students' individual learning styles and needs. They discussed the importance of presenting varied amounts of information and guidance. Dawn elaborated:

> I have some students that need a lot of information, a lot of guidance, and some of them kind of get almost bogged down by too much information. I present [instruction] in a consistent manner, but kind of layer it where they need more assistance.

The teachers maintained that it is important to scaffold instruction by modeling how to work through a graphic and then giving students a problem to work independently. Felicia shared:

> When I go back to a problem [with the student; for example], "Janet drew this isosceles trapezoid." [I'll ask,] "What does trapezoid mean?" Then I model what am I looking for in this problem.

Felicia went on to talk about supporting a student developing understanding a graphic that contained variables represented by letters in addition to numbers.

> For this graph it is *y* and *w*, so I would read the whole question and then explore the whole graphic [looking for *y* and *w*]. Find our letters. Now let's find all the numbers. Then look at the angles. It has a little arc at the angles. Then once we explored the graphic, go back to the question and read it.

Several teachers said they had students go back to the question, looking for cues to guide them in getting necessary information. According to Elle, ". . . [Students] get lost in the clutter . . . a lot of the time. We go back to the question and just write out what we know and what we have to find out."

Teachers discussed the importance of using the same language that the general education math teacher used. Elle explained:

> I use the same language [consistently] with my students and then I try to use the language of their general ed[ucation] teachers. So if they are saying *x-y* graph, or Cartesian, coordinate graph, whatever it is, that's the language that they hear from a few sources.

The teachers recommended providing timely prompts and feedback to encourage students to move through a problem involving a graphic. Elle pointed out: ". . . a lot of them are waiting for that prompt if they are right or wrong. They don't want to move on until they've heard that they are right."

Designing materials to teach graphic literacy

Participants were asked for their advice on designing an iPad app and materials to promote the development of graphics literacy for students who are both print and braille readers. Ideas shared included: making an app game-like, providing students with practice opportunities with materials, teaching systematic skills for gathering information from graphics, providing students with feedback as they work with the materials, and designing materials that are motivating. Carol stressed the importance of feedback for students. She said that the app itself could graph student progress, giving students a real-life graphing experience.

Jane suggested, "Anything said on the app should be able to be read [in braille. Students] can connect their electronic braille display and go back and forth between graphic and reading." The teachers felt that having multiple ways for students to access information is paramount. Kate said, "I have a student who needed all three media to be able to understand and gather information from different graphics." The teachers noted the importance of having an auditory description of the graphic that accompanies the print or braille hard copy graphic.

Discussion

The focus groups yielded a rich picture of the experiences teachers of visually impaired students have when supporting students in accessing and understanding information presented in graphics. For a student to be effective in gathering information from a graphic, he or she needs to be able to access the information in the graphic. For print readers, enhancing the visual aspects of graphics through highlighting, color choices, and increased contrast were strategies recommended. For braille readers, teachers recommended selecting tactually clear textures and placing labels in logical places. For both types of readers, the teachers noted the need to sometimes simplify the graphic. Their opinions align with the findings of Zebehazy and Wilton (2014c) and Rosenblum and Herzberg (2015), who each reported that although students felt positive about the quality of graphics they used, the density and complexity of some graphics posed challenges to them. It is critical for producers of both braille and print graphics to design the graphics so students can accurately and easily locate necessary information.

The use of low vision devices can increase visual efficiency and literacy skills for students with low vision (Bell Cay & Andersen, 2010; Holbrook, D'Andrea, & Wormsley, 2017). The teachers noted the importance of students using prescribed low vision devices to enhance their access to detail. Manipulatives, both those produced by APH and mainstream manipulatives available in schools such as wooden shapes, allowed these teachers to support student understanding of information presented in the graphics.

Common sense dictates that a student cannot solve a math word problem if he or she does not understand how to extract information from the word problem or how to complete the computation once the necessary information is extracted. Teachers of visually impaired students in a study by Zebehazy and Wilton (2014a) reported that basic concepts and background knowledge are essential for students to effectively work with graphics.

Teachers of visually impaired students are not math teachers; they are charged with providing students with instruction in the expanded core curriculum (ECC) (Lewis & Allman, 2014). However, teachers of visually impaired students often find themselves in the role of a general education teacher because their students need support in academic subjects. The need to balance their role so that their focus is on building ECC skills is an ongoing challenge (Lewis & Allman, 2014).

Koenig and Holbrook (1995) introduced the learning media assessment more than 20 years ago as a way to gather information about a student's use of learning and literacy media (Holbrook, Wright, & Presley, 2017). As the 11 teachers of visually impaired students in the focus groups indicated, knowing a specific student's sensory strengths and primary and secondary literacy medium for accessing information can aid in supporting them in gathering information from graphics. As part of the data-gathering process for the learning media assessment, these teachers should include opportunities for students to use graphics material.

Students who are successful in working with graphics are systematic in their approach (Rosenblum & Herzberg, 2015; Steele, 2015; Zebehazy & Wilton, 2014a, 2014b). To ensure students are systematic in their exploration, the materials must be legible. As Herzberg and Rosenblum (2014) concluded, inconsistency in how materials are presented can affect students' ability to access and understand the graphics. The teachers stressed the importance of braille readers using both hands in their exploration of tactile graphics, a strategy that Zebehazy and Wilton (2014b) also reported as valuable to success. The teachers noted that visually impaired students need to develop strategies for different categories of graphics, because the way in which a student approaches a bar graph differs from the method a student uses to approach a map. Future research that examines how successful students approach different categories of graphics, not just in a research setting, can provide a better understanding of graphic efficiency for both braille and print readers.

Developing success in interpreting graphics takes a varied skill set. Gina summarized nicely what it takes:

> Students who have really good literacy skills are able to generalize the information. . . . They have enough prior knowledge they can put it in their brains before they actually put their hands or their eyes on the graphic. They have already categorized things that they need and that's part of overall literacy skills. And then having spatial or muscle memory skills to know where to go to look for it.

Implications for practitioners

The 11 teachers of visually impaired students used a variety of strategies and techniques to support students in accessing and understanding information presented in graphics. It was clear to the researchers that although each teacher had developed her own beliefs and strategies, there is a need for curricular materials and guidelines to support teachers of visually impaired students in graphics literacy instruction beginning in the early grades. Zebehazy and Wilton (2014b) suggested that early development of skills that help students understand graphics is important for later success. Tools that allow students to gather information, practice using the information, and then apply the information within math contexts will enable them to get feedback on their approach to gaining information through graphics.

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