Braille and Tactile Graphics: Youths with Visual Impairments Share Their Experiences

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Structured abstract: *Introduction:* Data were collected from youths with visual impairment about their experiences with tactile graphics and braille materials used in mathematics and science classes. *Methods:* Youths answered questions and explored four tactile graphics made using different production methods. They located specific information on each graphic and shared their thoughts about the quality of the graphics. *Results:* Twelve youths in 6th to 12th grades participated. Almost all participants reported typically receiving braille materials and using tactile graphics in their mathematics and science classes. Participants varied in their accuracy in locating specific information in four tactile graphics. They all reported that what made a tactile graphic "good" was clarity of information. *Discussion:* The majority of the youths reported that occasionally they do not have access to mathematics and science materials at the same time as their peers. Some seemed concerned by the lack of materials, and others did not. The lack of materials may be problematic, since some of the students reported completing the assignments later or not at all. Youths overwhelmingly reported a need to have tactually distinctive elements in graphics. *Implications for practitioners:* Professionals should consult youths when preparing materials for them for use in mathematics and science classes. Additionally, youths who are tactile readers need direct instruction in how to measure objects as well as how to locate specific information in a variety of graphics prepared using different production methods.

Individuals with visual impairments are underrepresented in science, technology, engineering, and mathematics (STEM) fields, and students with visual impairments often have lower achievement in mathematics and science than their sighted peers (Cavenaugh, 2006; National Science Foundation [NSF], 2009; Rule, Stefanich, Boody, & Peiffer, 2011). Challenges to success in STEM subjects for students with visual impairments may be related to several factors. First, STEM subjects rely heavily on visual illustrations to portray complex information (Jones & Broadwell, 2008). Second, STEM subjects, especially mathematics, require conceptual understanding; the ability to reason inductively about data; and abstract, relational thinking (National Governors Association Center for Best

Practices and the Council of Chief State School Officers, 2010). Third, it takes more time and instruction to efficiently explore and interpret pieces of information simultaneously with the hands rather than the eyes when reading braille (Kamei-Hannan, 2009).

Although these are significant challenges, students with visual impairments can develop the necessary skills and perform at grade level with accessible materials, appropriate accommodations, and knowledgeable, supportive teachers (Rule et al., 2011). Students who read braille need to master the Nemeth Code of Braille Mathematics and Scientific Notation and, as they progress in their education, learn how to proficiently examine and interpret increasingly more complex tactile graphics.

Tactile graphics provide readers with critical information included in inkprint figures, charts, graphs, diagrams, or maps (Braille Authority of North America [BANA], 2010). According to the American Printing House for the Blind (APH, 2008), the purpose of a tactile illustration is to communicate an idea or information, not to replicate a visual depiction in a tactile form.

Data from the Graphics Research and Standards Project (GRASP) study was used in the creation of the BANA's guidelines for producing tactile graphics (Canadian Braille Authority [CBA], 2003). The GRASP researchers collected information about the perceptions, preferences, and needs of youths and adults regarding tactile graphics (CBA, 2003). Participants in the GRASP study reported that it was easier to identify an outlined shape if the line was solid, and to distinguish lines on graphics produced using thermoform rather than fuser paper (CBA, 2003). Participants reported that empty space between textures improved readability, but that spacing between bars on a bar graph did not affect ease in reading (CBA, 2003).

Although the findings of the GRASP study led to the development of guidelines to standardize the design of graphics, there is still considerable variation of tactile graphics used in elementary and secondary schools. The purpose of this study was to gather information directly from youths who read braille about their experiences with tactile graphics and the braille materials they receive in mathematics and science classes. The study sought to answer the following questions:

1. Do students who are tactile readers have access to tactile graphics, especially in mathematics and science classes?
2. Do students who are tactile readers have input into the preparation of the tactile graphics they receive?
3. According to students, what qualities comprise a "good" tactile graphic?
4. Can students who are tactile readers accurately locate and identify requested information in tactile graphics?

Methods

Participants

Approval to conduct the research was obtained from the Institutional Review

Board at The University of Arizona. The authors used a purposive sampling strategy to select "a sample from which the most can be learned" (Merriam, 2009, p. 77). The criteria to participate in the study were included in the initial recruitment e-mail on national and state electronic discussion groups to professionals in the field of visual impairment. The professionals were asked to share information about the study to students who met the list of qualifications. Criteria to participate in the study included: (a) being a student in 6th through 12th grades; (b) being within two grade levels in mathematics class; (c) residing in the United States; (d) being a proficient braille reader; (e) using braille as the primary literacy medium in mathematics and science classes; (f) having experience with tactile graphics; and (g) being articulate and comfortable sharing information with unfamiliar adults. Participants were recruited between February and April of 2013.

Procedures

In order to pilot test the questions and seek input about possible graphics, the authors conducted a focus group session in January 2012 with three youths in grades 4 through 12 about their experiences with tactile graphics. Based on the experience, the authors designed study procedures that incorporated individual, structured interviews and the use of four different tactile graphics. In January 2013 the first author completed individual in-person interviews with three youths. Data gathered from these interviews were reviewed by both authors and used to finalize procedures for the current study.

After receiving consent information and answers to a brief demographic survey for each participant, the first author scheduled a time and date to interview each youth. Participants were also sent an envelope containing four tactile graphics and a consumable ruler via U.S. mail. They were instructed to not open the package before the interview. During April and May 2013 the first author completed the structured interviews by phone. Each youth was asked a predetermined set of open-ended questions about their experiences, ranging from "What makes a good tactile graphic versus a bad tactile graphic?" to "What do you do if you're in class and you don't understand a tactile graphic?" Predetermined extension probes were asked to solicit more details, examples, and clarification as needed. Afterwards, participants were asked to complete a series of tasks and share their impressions regarding the clarity of the tactile graphics in their packets. Examples of tasks included: (a) measuring the length of the neck on the guitar; (b) determining how many people traveled to Hawaii in 2009; and (c) locating the country that is south of Libya. Examples regarding the clarity of the graphics included: (a) clearness of key and scale; (b) placement of labels, lead lines, or both; and (c) tactual distinctness of lines and areas. In an effort to put the youths at ease, they were free to choose the order of graphics discussed. The last question for each graphic was, "How could this graphic have been improved?" Although the interviews were not recorded, the first author took comprehensive notes on her laptop throughout each session. In the summer of 2013, the researchers analyzed the data by compiling the data for the open-ended questions and then carefully reviewing each response, looking for

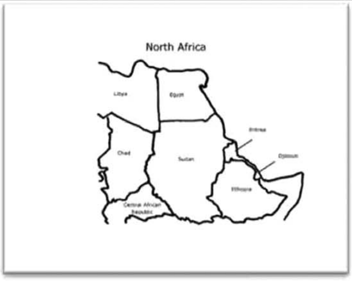
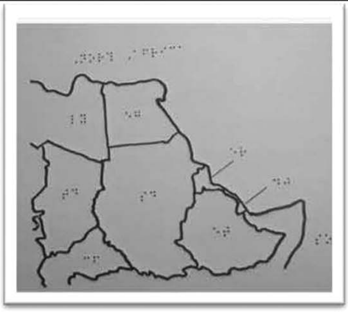
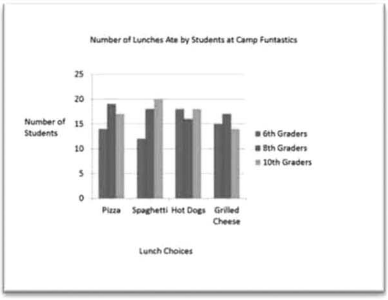
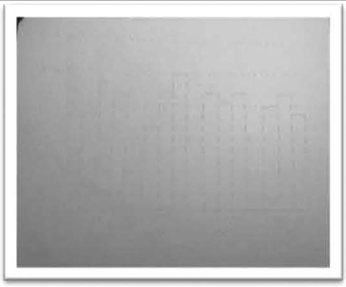
Production method	Print image	Tactile graphic
Microcapsule		
Computer-generated graphic		

Figure 1. Inkprint material and corresponding tactile graphics.

themes both within and among the questions (Merriam, 2009). The data for questions related to the completion of tasks was entered into an SPSS file, and then the researchers analyzed the data using descriptive statistics.

Graphics

Four graphics were designed by the authors, and each graphic was produced by identical methods so that all youths received the exact same graphics. Graphics were produced by methods commonly used to prepare graphics in Arizona and South Carolina schools. Three of the graphics and associated tasks might be used in mathematics, and one graphic contained a map that might be used in social studies (see Figure 1 for all graphics). Although not related to a STEM subject, a map was included since maps are routinely used in general education classrooms and are included within the Literacy for Social Studies and History State Standards for secondary students (National Governors Association Center for Best Practices & the Council of Chief State School Officers, 2010). Similar to the 2003 GRASP study by CBA, the production method for each of the four graphics was randomly selected by the authors.

A bar chart was produced as an embossed (also known as computer-generated) graphic. The y-axis was labeled "Number of students" with values of 0 to 25 in increments of 5. The x-axis was labeled "Lunch choices." Pizza was the only choice that appeared on one line. The word *spaghetti* was hyphenated across two lines and the second word for *hot dogs* and *grilled cheese* were both on the second line. Both the inkprint bar graph and tactile graphic contained gridlines.

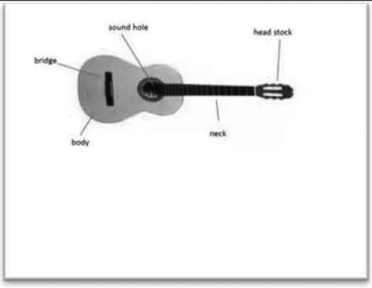
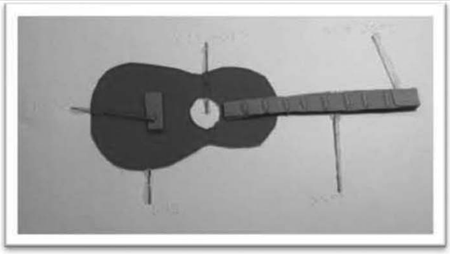
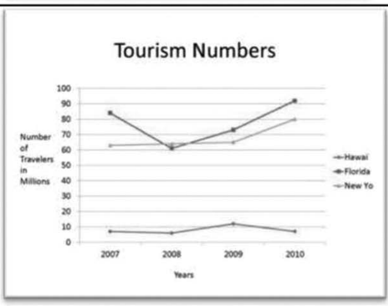
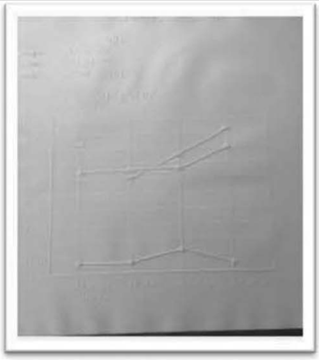
Production method	Print image	Tactile graphic
Collage		
Thermoform		

Figure 1. Continued.

A line graph was produced as a thermoform graphic. There were three lines on the graphic that showed the number of travelers in millions to each tourist destination. The y-axis was labeled "Number of travelers in millions" with values from 0 to 100 in increments of 10. The x-axis was labeled "Years" and had four values. Both the inkprint line graph and tactile graphic contained gridlines.

A picture of a guitar was produced as a collage graphic. It contained five tactually distinctive parts with lead lines made of hot glue indicating a braille label for each part. This graphic was used for measurement tasks.

A map of nine countries in Northern Africa was produced as a microcapsule graphic (also known as *fuser* or *capsule paper).* Labels for seven of the countries were placed inside the countries and the remaining two were placed outside the countries with lead lines from the labels to the countries.

Results

Participants

Fourteen youths with visual impairments in grades 6 through 12 consented to participate. One youth withdrew prior to the interview. A second youth completed the interview; however, it was determined that he did not meet the criteria as he had limited experience with braille and tactile graphics, so his data was dropped from analysis. This article reports the findings for 12 youths. Five were from Texas, two each from Ohio and Colorado, and one each from Arizona, Indiana, and Michigan.

Participants' parents reported the youths' demographic data at the time of consent.

Four were in 6th through 8th grades, 3 were in 9th or 10th grade, and 4 were in 11th or 12th grade. Eight participants were female, and 4 were male. Eleven youths attended public school and received services from a teacher of students with visual impairments; the 12th youth attended a specialized school for the blind. Nine youths were reported to be at grade level in mathematics, 1 was below grade level by a year, and 2 were above grade level. The eye conditions reported were Leber's Congenital Amaurosis ($n = 4$), retinopathy of prematurity ($n = 3$), a septo-optic dysplasia ($n = 2$), cortical vision impairment ($n = 1$), Peter's syndrome ($n = 1$), and cancer of the optic nerve ($n = 1$). Interviews lasted from 25 to 45 minutes. The first author took detailed notes during each interview.

Experiences in Mathematics and Science Class with Braille and Tactile Graphics

All participants reported receiving braille materials and using tactile graphics in their mathematics and science classes. Most reported occasional experiences with poor-quality braille and indicated that they have learned to work around errors. One 11th-grade participant said, "In about 80% of cases it will be a tiny obvious error and I'll be able to figure it out. Then there are real problem cases, [for example,] when the diagram is cluttered. If I concentrate, I can interpret what the diagram is supposed to be."

Participants were asked how they first approach an unfamiliar graphic. Several indicated they looked at the title and key first. A ninth-grade participant said, "I look for a title, and then I look for a key. I make sure to explore all parts of the page as much as I can. Some graphs are harder than others. I explore as much as I can from left to right and top to bottom. I look at the axis if there are different axes. I look at labels." Most participants reported first exploring the graphic before looking at the title or key. For example, another ninth-grade participant said, "Generally I take a general look at . . . its shapes and lines. After that I'll check out the key and the questions that go with it. I will look at the title if it is relevant or I am confused."

Several commented on the need for graphics to contain essential information. An 11th grader said, "If my braille teacher tried to draw every picture she would be there until midnight. With the volunteers [who produce graphics for] mathematics you have an x-y graph on a grid. They don't draw the grid. They just draw the x and y axis. They don't put the numbers on the graphic and I wonder how am I supposed to count. They draw the figure, I have to measure on the print paper, and it is so small I can't line my ruler up and I can't feel the edge of the line."

Of the 12 participants, only two 11th graders and one 7th grader reported that they have been asked to give input on the development of graphics for their use. One of the 11th graders said that he is sometimes asked if he would prefer a description rather than a graphic and the other 2 reported they are asked about their preferences of textures for different elements. Three more commented that individuals preparing graphics for them knew what worked for them. The other 6 reported that they had no opportunity to provide input.

All participants indicated that they ask for help from a sighted individual when information in the graphic is not clear while in mathematics or science class. If the teacher of students with visual impairments or paraeducator is present, this is the first person participants ask. If that individual is not available, they often ask the general education classroom teacher. Two participants reported that they ask classmates for information.

Participants were asked how they respond when they do not have materials being used in their mathematics and science classes. A range of emotions was expressed from anger and frustration to feeling relieved that one did not have to do the assignment. An eighth grader had the strongest reaction to this question: "I hate that!!! . . . I like to see what is going on. I am clueless if I have to have someone read it to me. I have to read it myself to help my understanding." A ninth grader's response was typical of those participants who were not bothered when they did not have the material in braille: "I really don't care because I'm still able to participate in the assignment and I still get the job done." She then gave examples of being given an alternative assignment or receiving the assignment in braille several days later to complete. Many participants explained strategies they use when they do not have the graphic, including having someone draw the graphic on the spot with a tool such as the Draftsman; asking for a verbal description; having the graphic shared with the teacher of students with visual impairments, paraeducator, or braillists to be prepared for later use; working with a classmate; receiving an alternative assignment; or having the general education teacher e-mail the assignment so it can be accessed on the participant's computer or portable notetaker.

The participants were asked to define what made a "good" tactile graphic. As one 10th grader stated, "A good tactile graphic has all the important parts labeled clearly, with a different texture for each part. It needs to be easy to figure out. A key is very central with all the different textures labeled. Make sure it is on good sturdy paper. . . . A bad tactile graphic is on flimsy paper or the lines aren't raised enough or [there is] not enough info on the key." Overwhelmingly, participants talked about the need for tactual clarity on a graphic for it to be considered "good." They described ”good‘ tactile graphics as having different textures for different parts, lines that were distinct from each other, clear braille, a logical key, and being free of clutter.

Tactile graphics

Microcapsule

All participants explored the map of Africa and then answered a series of questions (see Table 1). Eleven of the 12 participants reported that they looked at the title before the map, while a 12th grader reported reading the key prior to the title. Ten participants felt the labels were clear. Although all participants felt the key was clear, 2 participants felt the labels would have been clearer if different letter combinations had been used for some of the countries. Seven participants felt the labels were not too close to lines designating the countries, but the other 5 felt some labels were too close to lines. Suggestions for improving the graphic included deleting lead lines to the smaller countries, using accurate labels (for instance, not using "TD" for Chad), and presenting the

Table 1
Number and percentage of participants who correctly answered each question.

Question	Correct answers n (%)
Microcapsule map	
How many countries are shown on this map? (*n* = 12)	10 (83.3)
What country is north of Sudan? (*n* = 12)	12 (100.0)
What country is south of Libya? (*n* = 12)	11 (91.7)
What is the smallest country on this map? (*n* = 12)	5 (41.7)
Bar chart	
How many foods were eaten at lunch? (*n* = 11)	8 (72.7)
How many 8th graders ate spaghetti? (*n* = 10; responses between 15 and 20 were considered correct; none of the participants responded with the intended answer of 18)	8 (80.0)
How many 10th graders ate grilled cheese? (*n* = 9; responses between 10 and 15 were considered correct; none of the participants responded with the intended answer of 14)	6 (66.7)
How many 6th graders ate hot dogs? (*n* = 10; responses between 15 and 20 were considered correct; none of the participants responded with the intended answer of 18)	8 (80.0)
Line graph	
How many people traveled to Hawaii in 2008? (*n* = 10; responses between 5 and 10 million were considered correct; none of the participants responded with the intended answer of 8 million)	7 (70.0)
How many people traveled to New York in 2008? (*n* = 10; responses between 60 and 70 million were considered correct; none of the participants responded with the intended answer of 62 million)	6 (60.0)
How many people traveled to Florida in 2009? (*n* = 10; responses between 70 and 80 million were considered correct; none of the participants responded with the intended answer of 72 million)	5 (50.0)
Collage	
What is the length of the entire guitar? (*n* = 12; guitar measured 8 inches or 19 centimeters)*	4* (33.3)
What is the length of the sound hole? (*n* = 11; sound hole measured approximately 1/2 inch or 2 centimeters)	4 (36.4)
What is the length of the head stock? (*n* = 12; head stock measured 1 inch or 3 centimeters)	2 (16.7)

* In addition, one participant said the guitar was longer than six inches but did not give an exact measurement.

key and map side by side rather than stapling them. BANA (2010) states Chad is to be abbreviated TD.

Embossed

The participants were then asked a series of questions about the bar graph. Three participants declined to answer some or all of the questions, as they found the graphic confusing. See Table 1 for information about the number of participants who correctly answered each question. Participants were also asked how they located the lunch choices. Nine participants reported they found the x-axis and read the lunch choices, one used the key in combination with looking at the items on the x-axis, and the final participant said, "The numbers were on the side." The researcher questioned further and discovered that the participant was looking at the y-axis.

Overwhelmingly, participants reported that the columns on the bar graph were not tactually distinctive. Participants had considerable feedback on how this graphic could be improved. First and foremost, seven participants gave very specific feedback about the need to use different textures for each of the columns. Three participants also felt that the label for the lunch choice "spaghetti" should not have been divided across two lines, and three others commented that the gridlines were confusing. One participant suggested the graphic be divided into three separate graphics, one for each grade level. Another recommended that the number of campers eating each food choice be written above the bar.

Thermoform

Eleven participants initially reviewed the thermoform graphic, and they correctly identified that there were three travel destinations by examining the key. Of the 11 participants, 8 reported that they read the title before feeling the lines on the graphic. Ten out of the 11 then looked for specific data on the graphic and answered a series of questions (see Table 1). Half of the participants thought the line textures used on the graphic were clear. The other half reported it was difficult to distinguish which line represented which travel destination. An 11th grader noted that the lines for Florida and New York were close together; however, this is the way it was reported in the inkprint copy as well. There was an overlap of these two lines for the year 2008.

Participants were asked how this graphic could be improved. One sixth grader suggested not using thermoform because this material "dulls the information." Four participants suggested that either more space be left between the lines or that tactually distinctive lines be used to represent each travel destination. A ninth grader felt a clearer key should be developed. Two others suggested using tactually distinctive symbols for each year on the line for each destination. Finally, an eighth grader suggested the data would be presented more clearly in a bar graph.

Collage

All 12 participants answered questions about the graphic. Eight of the 12 participants reported they read the title before they explored the graphic. One reported having sufficient vision to identify the shape as a guitar. Eleven of the 12 correctly identified the graphic as having five labeled parts. Nine participants felt the labels for the parts of the guitar could easily be identified with the parts to which they belonged. Two participants stated that the labels were somewhat clear and one participant said the label for the head stock was not clear. Participants were then asked to complete three measurement tasks. A throwaway ruler used from APH included both centimeters and inches in half-inch increments. Table 1 provides information about the number of participants who correctly measured the items.

A sixth grader suggested that omitting the lead lines would improve the graphic. An eighth grader said the graphic needed a better title. A 12th grader said that he would have moved the bridge label. A ninth grader suggested that the lead line for the sound hole go directly to the center of the sound hole. However, the graphics were prepared with the lead line going to the center of the sound hole.

Discussion

Twelve youths who read braille shared their experiences with tactile graphics in mathematics and science classes. The youths were extremely articulate in describing the strategies that they use to locate information on a graphic and in offering suggestions on how the provided graphics could be improved. The vast majority of youths reported that there are times when they are not provided with materials in braille at the same time as their sighted peers. Not surprisingly, the youths handled this situation differently. The authors were encouraged that each youth could share specific strategies that they use, such as asking for a verbal description or asking that the graphic be shared with their teacher or transcriber.

Limitations

The study had several limitations. First, neither author was present to observe how the youths explored and gathered information from the four tactile graphics. Second, data were not gathered about the intensity of services the youths received from a teacher of students with visual impairments or if they had someone physically with them during mathematics and science classes (for instance, a teacher of students with visual impairments or a paraeducator). In addition, very limited information was gathered about the mathematics and science classes they attended. Third, most of the youths were unfamiliar with the ruler from APH, according to their comments as they completed the measurement activities. It is possible that youths may have been more accurate in their measuring if they had used a ruler familiar to them. Fourth, conclusions regarding preferences for production methods could not be drawn. Since different content was used for each graphic in the study, preferences about production methods could not be separated from the task difficulty or content preferences. Fifth, a Likert scale was not used to quantify responses such as occasionally or frequently. Sixth, interrater reliability was not conducted. And finally, there was no triangulation of data. The study would have been strengthened by in-person observations, interviews with teachers of students with visual impairments, or access to student school records.

Measurement

The authors were surprised by the range of measurements provided by the youths when they were asked to measure objects on the collage graphic. Some youths did question if measurements were to be in inches or centimeters, and they were told either unit of measurement would be fine. When inaccuracies occurred, all the youths tended to report lengths longer than they were in actuality. It appeared that some of the youths did not estimate to confirm the reasonability or accuracy of their measurements. It is probable that unfamiliarity with the ruler and its small size may have contributed to the inaccuracies; however, one would expect a student in grades 6 through 12 who is at grade level in mathematics to be able to measure items of various lengths in either inches or centimeters. According to common core state standards (2 Measurement & Data A1 and 2 Measurement & Data A3), by the time students complete second grade they should be able to estimate and measure the length of an object in inches and centimeters using a ruler (National Governors Association Center for

Best Practices and the Council of Chief State School Officers, 2010).

Precision with locating information on the x-axis and y-axis

Both the line graph and bar chart contained x-axes and y-axes. Youths reported that they could locate necessary information on the x-axis, but they often reported difficulty locating specific information on the y-axis even though there were gridlines. Not surprisingly, they were less accurate in answering questions that required them to locate specific information on the y-axis. They sometimes offered a range (for instance, 15 to 20 when the answer was 18) or an estimate rather than a specific number.

Implications for practitioners

Few youths had input into the types of graphics they receive—specifically, the way graphics are organized or prepared, textures that are used, or methods of orientating the youths to a new type of graphic (for instance, production method or content). Most youths indicated they preferred graphics that had clear distinctions between elements. Professionals may find that youths are more efficient tactile graphics readers if they are given an opportunity to provide input on the production of graphics. Similarly, their efficiency may improve if a systematic introduction of new types of graphical materials is used.

Some inadvertent observations were made, including finding a high number of youths who could not tell us the roles of the adults they worked with at school. Several students did not know if the person working with them in mathematics or science was a paraeducator or a certified teacher. It is important that youths be involved in their education, including attending individualized education program (IEP) meetings where roles and responsibilities are discussed.

Youths were keenly aware of the accuracy of their skills. They questioned themselves when attempting to locate specific information on the bar chart and line graph, but they rarely questioned themselves when answering questions about the map. Both authors have observed a tendency by some teachers of students with visual impairments to not always give youths with visual impairments accurate information and specific feedback about their skills. The students need to know when they are and are not accurate when completing any task. Students with visual impairments may need additional time and direct instruction to learn skills related to measurement and interpreting line graphs and bar charts. Finding functional and fun ways to incorporate this type of practice into both the core and the expanded core curriculum is essential.

If youths are expected to succeed when they transition into post-secondary education or employment, then it is imperative that they have the ability to articulate what works and what does not work for them. Including self-determination goals on the IEP is one avenue to ensure that these necessary skills are being addressed. The authors were pleased that students were able to articulate very clearly their preferences in graphics as well as how they used a variety of strategies to participate in class when they occasionally did not have materials in braille.

Future research

Future studies are needed that incorporate direct observation of youths using tactile graphics that correlate to the current curriculum that they are learning. A follow-up study similar to the study reported here that uses graphics reproduced using different methods (for instance, microcapsule graphic or collage) would allow researchers to learn if specific types of graphical content or specific types of production methods are more challenging for youths. In addition, with the increasing affordability and availability of three-dimensional printers, research is needed to determine if the use of these printers would be an effective production method for graphical and visually displayed information.

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